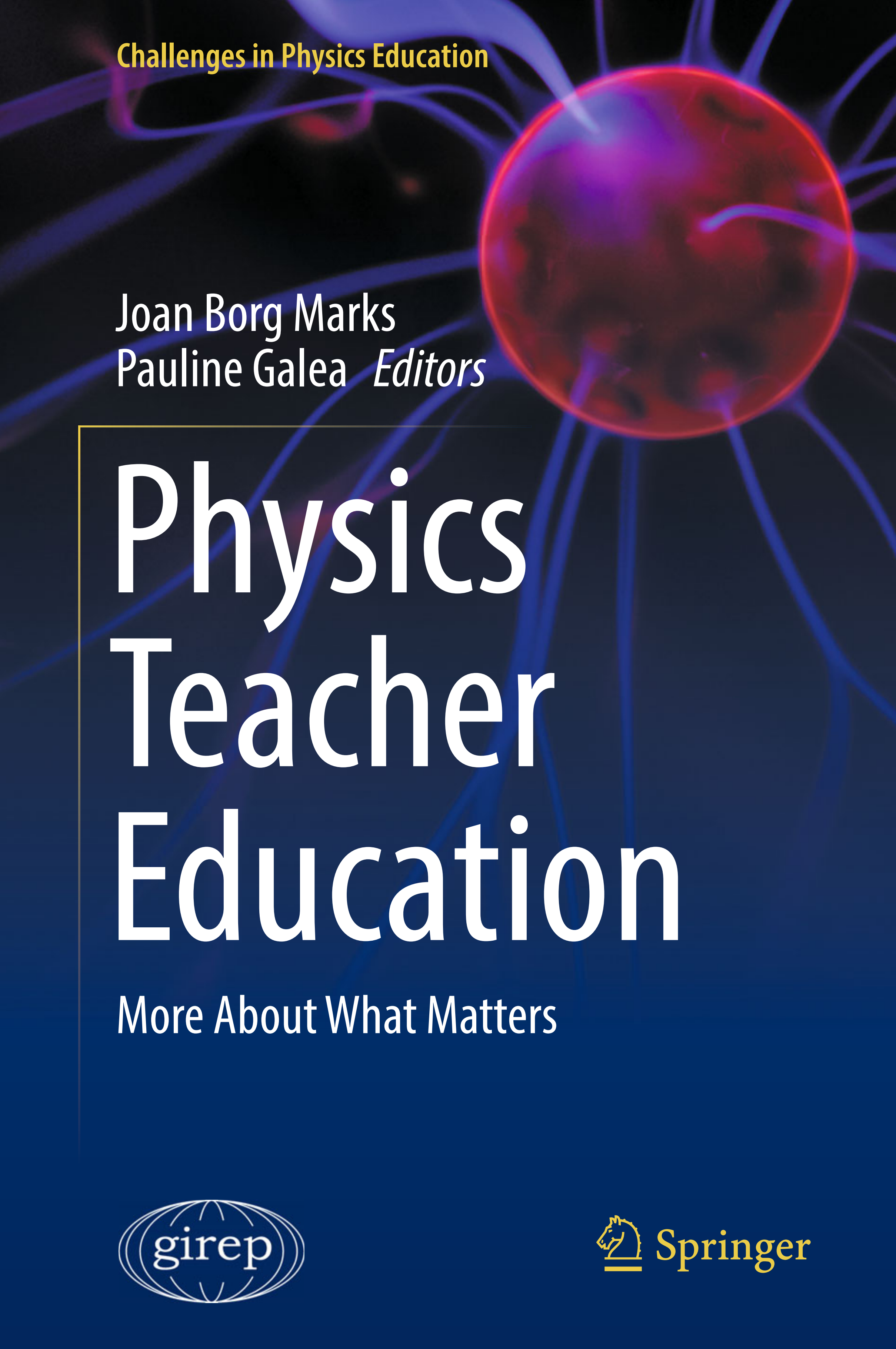


Challenges in Physics Education

Joan Borg Marks
Pauline Galea *Editors*

Physics Teacher Education

More About What Matters

girep

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
Editors

Physics Teacher Education

More About What Matters

Springer

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

Pauline Galea
Faculty of Science
Department of Geosciences
University of Malta
Msida, Malta

ISSN 2662-8422 ISSN 2662-8430 (electronic)
Challenges in Physics Education
ISBN 978-3-031-44311-4 ISBN 978-3-031-44312-1 (eBook)
https://doi.org/10.1007/978-3-031-44312-1

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Switzerland AG 2023

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

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

Paper in this product is recyclable.

Introduction

Initial Plans and Actual Practice

Some years ago, in the name of the University of Malta, it was proposed that a GIREP (Groupe International de Recherche sur l'Enseignement de la Physique) Seminar be held in Malta. Later when the GIREP Board accepted this proposal, little could we envisage that what was being planned as a Seminar was to later transform itself into two consecutive Webinars taking place in 2020 and 2021. The circumstances did not allow for the possibility of face-to-face meetings, due to the COVID-19 pandemic. Thinking back, even if GIREP participants only made it virtually to Malta at that time, on a personal note, it can be said that GIREP could not have chosen a better title to give to these two webinars:

Physics Teacher Education—What Matters?

The focus of these meetings was on physics teacher education, highlighting the importance of teacher preparation (both pre-service and in-service) that leads towards enhancing students' meaningful learning. During the webinars, it was a real pleasure to have so many international professionals, including researchers in the field of physics education, participating in the events. All directed their interests and efforts towards the chosen topic, exploring the field, discussing and presenting their views and strategies used to help indicate innovative ideas that may hopefully lead to the understanding of what really matters in physics teacher education.

About Physics

Physics is one of the topics at school which most students find quite challenging. Generally speaking, when one mentions the study of physics, quite often, people—both young and old—say, that they had a hard time during physics classes. This perception is sometimes seen to exist even with some students at a very young age.

Learning physics involves having the learner proceed along a path which results in conceptual changes from the common sense ideas to the scientific ones representing phenomena. This is not always easy for all. Physics teachers thus need to be well prepared to be able to help their students learn this subject effectively—a subject that is fundamental to understanding that science is all around us.

About Teaching and Learning

It seems obvious that teachers are there to teach. How can students learn concepts unless teachers teach it to them? Indeed, I have always had the conviction that teachers are key to students' learning and understanding. Teachers have a very important role. But then, not only do they themselves need to believe that they are doing their job correctly, but this idea must be matched with students' perceptions that their teachers are doing their best to help bring about learning. The effect of teaching on learning must be visible. Much has been said about this by John Hattie (2009) in his book entitled 'Visible Learning.' Teachers need to bring passion into their teaching and understand when students find difficulty in constructing meaning. One of the aims of the GIREP Malta Webinar 2021 was to help improve motivation towards teaching and learning through the dissemination of innovative research in physics, possibly leading to more informed planning of teacher development programmes.

About Papers in This Book

A previous publication entitled 'Physics Teacher Education: What Matters?' presented ideas emerging from the GIREP Malta Webinar 2020. In this second publication, we are presenting the best contributions from the GIREP Malta Webinar 2021.

A number of keynote speeches were presented through the second Webinar and related papers are included in this book. Topics are related to the role of metaphors used in Physics teaching, the interaction of young children with Physics at primary level, connections that exist between Physics and Mathematics, and developments in teacher education in the USA.

Moreover, participants presented their research related to physics teacher education and physics teaching, and some of this research is also being presented here. Furthermore, discussions were conducted in various work groups with a focus on:

- Preparing teachers for TPACK (technological, pedagogical and content knowledge) and Lab work;
- Developing and evaluating teacher PCK (pedagogical content knowledge) in Quantum Mechanics;
- In-service physics teacher education for early childhood and primary levels;

- Pre-service physics teacher education at all levels;
- In-service physics teacher professional learning for second and higher level education.

The workgroup leaders of the respective groups prepared position papers based on what was discussed and these have also been included. Chapters in this book inevitably look into how physics teacher education is organised in different countries. Suggestions are offered related to possible ways of supporting physics teachers' learning. An emphasis is made on the much-needed measurements of the effectiveness of different teaching strategies that improve teaching for learning.

In Conclusion

This book should help professionals involved in physics teacher training, researchers and pre-service and in-service teachers to get acquainted with the most recent research contributions in Physics teacher education. It is hoped that ideas presented in this book will be of help in creating effective physics teacher professional development programmes that are not there by coincidence, but which happen because of careful planning, after looking at details from research studies conducted within classrooms and further disseminated internationally, within communities like GIREP.

It is augured that this work will help foster learning spaces in schools and universities in line with John Hatties' model of Visible Teaching—Visible learning. This happens:

> When teachers SEE learning through the eyes of the student;
> When students SEE themselves as their own teachers. (Hattie 2009, p. 238)

Joan Borg Marks
Faculty of Science
Department of Physics
University of Malta
Msida, Malta
joan.borg-marks@um.edu.mt

Reference

Hattie J (2009) Visible learning: A synthesis of over 800 meta-analyses relating to achievement. London and NY: Routledge

Contents

Papers from Keynote Contributions

Position Papers by Workgroup Leaders

Initial Teacher Training

Teaching Approaches to Facilitate Learning

Papers from Keynote Contributions

The Role of Metaphors in Teacher Education in Physics

Federico Corni

Abstract Conceptual metaphor is one of the fundamental tools of our figurative mind. It is important to realize that metaphoric thinking is not a means of avoiding formal scientific thought so that a child or a layperson would understand what we are talking about. Properly understood and applied, metaphor creates the foundation for proper formal thought. Consequently, teachers should be introduced to figurative thought and to its power for education. This should help them develop a deeper understanding of the discipline and the ability of speaking and listening to their pupils. This paper is a contribution to the diffusion of such an approach to physics and to physics education. After a synthetic introduction to conceptual metaphor theory, examples of application in physics and in research projects in teacher education will be supplied.

1 Introduction

Traditional physics courses, and even courses based upon recent advances in the application of cognitive science to physics education, do not suit the needs and motivations of student teachers at kindergarten and primary school levels. Student teachers need to learn science and physics in an elementary, but foundational and scientifically rigorous way, to consider physics as relevant to their future work and to feel able to translate their learning into everyday didactic practice (Shulman 1986; Park and Oliver 2008; Gess-Newsome et al. 2015; Karal and Alev 2016; Kulgemeyer and Riese 2018; Kind and Chan 2019). Student teachers should be exposed to experiencing natural and technical processes leading to a form of primary physical science in a way that parallels that of the children they would be in charge of, that relies on the elementary conceptualizations basic to human thought (from children to adult, from common people to scientists) and that is respectful of their prevalently humanistic background. Here, we use the term *primary* in a dual sense. It means *early* in the

---

F. Corni (✉)
Faculty of Education, Free University of Bozen-Bolzano, Bolzano, Italy
e-mail: Federico.Corni@unibz.it

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2023

J. Borg Marks and P. Galea (eds.), *Physics Teacher Education*,
Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-44312-1_1

sense of education for children when they build their primary understanding of the world, and it refers to the understanding of concepts of science that may rightly be called primary, i.e. the concepts and ideas that form the *roots* of scientific thought and theories.

The reason for evaluating conceptual metaphor in education, in general, and in teacher education in physics, in particular, can be found in the George Lakoff quotation: "The discovery of conceptual metaphor independently by M. Reddy and myself [George Lakoff] in the late 1970s showed that metaphor is primarily conceptual, and secondarily linguistic, gestural, and visual"(Reddy 1979; Lakoff and Johnson 1980; Lakoff 2014). After the seminal works of Lakoff and Johnson (1980, 1999), Lakoff 1987), metaphor can no longer be considered simply a rhetorical figure, but a real tool for understanding, or the human way of thinking and communicating, from early childhood to adult age. The symposium "Conceptual Metaphor and Embodied Cognition in Science Learning" held at the conference of the European Science Education Research Association (ESERA) in September 2013 was one of the early indications of interest in conceptual metaphor theory in science education. The symposium was proposed by Tamer G. Amin, Fredrik Jeppsson, and Jesper Haglund who edited the homonym 2015 special issue of the International Journal of Science Education.

Macroscopic physics is full of metaphorical expressions (Fuchs 2006, 2010, 2013; Corni et al. 2012, 2013)—they are unavoidable: for example, energy is conceptualized as a metaphoric *substance*, when we say that the energetic problem is not a matter of *quantity* but of *storage and distribution of the large amount* of energy coming from the Sun; or temperature is conceived as a *vertical scale*, when we say that it *rises*, or it *falls* (it is not by chance that a thermometer is normally hung vertically on a wall, even if it would work also horizontally). This has a significant impact on teaching/learning a conceptual discipline like physics. An emphasis on metaphors, besides allowing for a simplification of the discipline, allows for the humanistic background of student teachers to be valorized and fruitfully exploited. If we assume that the human mind (of pupils, teachers, and scientists) works imaginatively and uses metaphors to conceptualize, then the theory of conceptual metaphor and its implications in education assume an important role in instruction and deserve to be ingredients in the preparation of kindergarten and primary school student teachers in physics.

It should be clear from the beginning that a metaphorical approach to physics has nothing to do with a pictorial oversimplification of the discipline for the purpose of making it understandable to children and their teachers. Rather, the discipline is seen under a new light, where the elementary pillar conceptualizations are understood figuratively and the discipline is integrated into the whole primary education process.

In Sect. 2 of this paper—"Conceptual metaphor theory"—we will hint at some notions of conceptual metaphor theory. Then, in the following Sect. 3—"Conceptual metaphor in physics"—we will illustrate two examples of application of metaphor theory to Physics, i.e. in the case of the concept of energy and in the continuum physics paradigm. Finally, in Sect. 4—"Examples of research projects in teacher education in physics"—we will report from two research projects on conceptual metaphor in physics teaching/learning with student teachers of kindergarten and primary school grades. Section 5—“Summary”—will synthesize the main points raised in the paper.

2 Conceptual Metaphor Theory

We like to think that what we say, think, and understand refers directly to an external reality: language and thought are assumed to be literal. However, the large majority of linguistic expressions we use show that our mind must be working (mostly) figuratively, making use of metaphors.

Conceptual metaphor theory was originally developed by Lakoff and Johnson (1980, 1999). They argued that our conceptual system develops through personal, physical experiences. At the most basic level, we form *image-schemas*, knowledge gestalts that emerge out of repeated and pattern sensorimotor experiences when interacting with the surrounding world (Johnson 1987; Hampe 2005). An image-schema is a condensed re-description of perceptual experience for the purpose of mapping spatial structure onto conceptual structure. Examples of image-schemas include the *container schema*, in which we conceptualize an inside, an outside and a separating boundary; the *source-path-goal schema*, through which we conceptualize an object moving along a path; and the *substance schema* which we use to give existence to abstract concepts. Image-schemas can be thought of as mind bricks and are available to everyone, from the early years of life. A list of the main image-schemas can be found in Fuchs (2009); Corni et al. 2022). Complementary researches in neuroscience, cognitive psychology, and cognitive linguistics over the years support the theory of conceptual metaphor (Amin et al. 2015; Gibbs 2005).

A conceptual metaphor is a figurative comparison in which one (target) domain of experience is (partially) understood by the projection of an embodied understanding of another (source) domain (Lakoff and Johnson 1980, 1999). Source in metaphors can be any known domain; if, in particular, sources are image-schemas, the metaphors are called primary. Metaphors are very common, so much so, that we use them unconsciously. An example of metaphor is TIME IS MONEY (small caps are conventionally used to indicate a metaphor) where *Time* is the target domain to be characterized and *Money* is the source domain used to specify some aspects of *tTime*. Based on this metaphor, we formulate in our speech several expressions that are metaphorical (even if it could not seem so to us) and that construct the meaning of time from disparate points of views as a valuable thing. We say: “don’t spend too much time on that task”; “travelling by train saves time”; “investing time in study, sooner or later comes in handy”; “you waste my time”; “earning time”; and many other phrases like these. Note that in a metaphor the two nouns cannot be exchanged. MONEY IS TIME doesn’t work or does not have the same meaning. Other examples of conceptual metaphors are IDEAS ARE FOOD, ARGUMENT IS A WAR, PURPOSES ARE DESIRED OBJECTS, etc. A *primary* metaphor for time, for example, is TIME IS A PATH (path is an image-schema), where we are moving on, or that we, standing still, see passing in front of us. So, we say: “I went through many years of studying climate" or "when we are happy, time passes too quickly". In short, the concept of time is figurative: we would not be able to conceive time in the absence of the (embodied) source domains we use in our metaphorical expressions. No one, neither physicist, philosopher, neuroscientist, economist, etc. knows what time really is, but everyone, educated and lay persons, have and efficiently use (figurative) meanings of time. Some other examples of primary metaphors, with reference to the field of physics, are BODIES ARE CONTAINERS OF HEAT, PRESSURE IS A VERTICAL SCALE, ELECTRICITY IS A FLUID- LIKE SUBSTANCE.

We should become aware of the fact that, especially for abstract concepts, metaphorical understanding is unavoidable. Many linguistic expressions, in common language (Corni et al. 2019), in scientific language (Fuchs 2013), and even in mathematics (Lakoff and Nunez 2000), are the result of such a mental operation. Besides, it is worth pointing out that a metaphor or a metaphoric expression (a linguistic expression descending from a metaphor) does not define a topic exhaustively, the more complex or abstract, but highlights some aspects of it and, in doing so, may obscure others (Lakoff and Johnson 1980, 1999). In other words, metaphor theory emphasizes the inadequacy of the myth of objective or of literal thought. Many abstract concepts are too complex to be described by a single metaphor. Several metaphors are needed that illustrate complementary aspects of the concept, though employing different images. Using the traditional Indian story of the blind men who attempt to learn what an elephant is, each one touches a different part, thus having a different understanding of what an elephant is (Lancor 2014): the elephant is the "sum" of their images, the individual images are partial, even inconsistent with each other. Energy is one of these very complex concepts in physics: there are various, even inconsistent, conceptual metaphors for energy (see Sect. 3) and their coherence is ensured by the fact that there is a theme that runs throughout science, but its exact nature depends on the particular context in which it is employed (Lancor 2014).

A frequent objection to the emphasis on conceptual metaphors in physics education is that the use of imagery may foster or consolidate students' misconceptions. This is questionable from at least two different perspectives. First, we must remember that source domains in metaphors are (used as) abstractions. Image-schemas, the main sources we mean in this paper and in physics in general, are gestalts our mind creates out of sensorimotor experiences no one would apply literally. It is out of doubt that if we hear that temperature is rising all over the Planet, we don't understand that temperature is concretely going upwards, or if we hear that electricity flows, we don't think it spreads out of the battery or wires and that it wets the surrounding surfaces. On the other hand, who has never said or heard these metaphorical expressions even in a scientific context? Taken positively, teachers who are aware of and sensitive to metaphors embedded in speech are in a more favorable position to grasp students' thoughts and conceptions from their talks and gestures. Secondly, we have to resign ourselves to the Lakoff quotation concerning the nature of thought and language. Metaphoric projection is at the roots of the functioning of our mind and language mirrors our mind. Those who advocate an objective, abstract, literal teaching should first confront this reality.

Note that there is a clear distinction between metaphor and analogy. An analogy is a mapping between two domains made possible by the fact that they are metaphorically understood using the same source domain(s) (Fauconnier and Turner 2002). For example, we say that *electric circuits are like hydraulic circuits*, because we subtend that ELECTRICITY/WATER IS A FLUID- LIKE SUBSTANCE, and ELECTRIC/WATER CIRCUIT IS A CYCLE where *fluid-like substance* and *cycle* are image-schemas. So, the two domains become similarly structured by the correspondences created by the shared metaphor(s): electric wires correspond to (are mapped onto) water pipes, batteries, or electric generators to hydraulic pumps, electric resistance to hydraulic resistance, etc. Note that unlike a metaphor, the two nouns in an analogy can be interchanged while retaining the meaning, e.g. we can say that *hydraulic circuits are like electric circuits.*

3 Conceptual Metaphor in Physics

In this section, we will illustrate two examples taken from literature, among many others, of application of metaphor theory, showing how science and physics, like any other products of the human mind, are metaphorical in nature, and pointing out some didactic arguments. We will first treat the concept of energy (Lancor 2014, 2015; Amin 2009), then we will analyze the paradigm of continuum physics (Treusdell and Toupin 1960; Treusdell and Noll 1965; Eringen 1971).

3.1 The Concept of Energy

Lancor (2014, 2015) analyzed scientific textbooks and the science education literature in biology, chemistry, and physics following Lakoff and Johnson (Lakoff and Johnson 1980, 1999) conceptual metaphor theory and found that the vast majority of discourse about energy implies that it is a substance. Although widely accepted that energy is not actually a substance, it is virtually impossible to discuss energy without referring to it as a tangible quantity. She categorized six primary conceptual metaphors:

1. ENERGY IS A SUBSTANCE THAT CAN BE ACCOUNTED FOR,
2. ENERGY IS A SUBSTANCE THAT CAN CHANGE FORMS,
3. ENERGY IS A SUBSTANCE THAT CAN FLOW,
4. ENERGY IS A SUBSTANCE THAT CAN BE CARRIED,
5. ENERGY IS A SUBSTANCE THAT CAN BE LOST FROM A SYSTEM,
6. ENERGY IS A SUBSTANCE THAT CAN BE STORED, ADDED, OR PRODUCED.

None of these metaphors exhaustively defines energy. Rather they work together to illustrate complementary aspects of the concept. Moreover, remembering the nature of metaphor, each of these highlights and obscures the characteristics of energy to varying degrees. For example, the first metaphor highlights the conservation and obscures the transformation characteristics of energy; the second one highlights the conservation and obscures the transfer characteristics, etc.—see Table 3 in Lancor (2014). Taken individually, these conceptual metaphors are commonly considered students' misconceptions or alternative conceptions (Watts 1983), but in a more comprehensive way, we should say that students have an incomplete understanding of energy and recognize that energy is a conglomerate of these ideas. Viewed from a different perspective, each conceptual metaphor explains the role of energy in a particular context and so none of these can be assured as definition (if any) of energy. From a didactic point of view, the substance metaphors for energy are grounded in a territory that is more familiar to students and thus, more useful for helping them build a productive framework for understanding energy. Many educators recognize that substance metaphors are not harmful to students' understanding of energy (Duit 1987; Falk et al. 1983). Care must be taken when using these metaphors in the classroom so that students do not take them literally.

Amin (2009) detected other metaphors used for energy, in addition to the substance one. He analyzed, in terms of conceptual metaphor, the lay and scientific use of the noun energy by comparing, on one side, the findings in 200 sentences randomly selected from the British National Corpus and, on the other side, in 150 sentences randomly selected among those drawn from The Feynman Lectures in Physics Volume 1 and 2 (Feynman et al. 1963).

In everyday expressions, some literal expressions are found besides the metaphorical ones due to the conceptual overlap between energy and energy sources or carriers. Scientific expressions are all metaphorical, in agreement with the fact that energy is an abstract concept, and one cannot talk about it properly except by resorting to figurative language. The metaphors found by Amin are summarized in Table 1, where we indicate the provenance from every day or scientific discourse, or both.

Amin finds a "… substantial overlap among the two sets of construals. When viewed from a conceptual metaphor perspective, this overlap, together with the

Table 1 Metaphors for energy in everyday and scientific discourse. From Amin (2009)

<table>
<tr><th>Everyday discourse</th><th>Scientific discourse</th></tr>
<tr><td colspan="2">More energy is up and less energy is down</td></tr>
<tr><td colspan="2" align="center">Object event structure metaphor</td></tr>
<tr><td colspan="2" align="center">Elaborations of object event structure metaphor</td></tr>
<tr><td></td><td>Location event structure metaphor</td></tr>
<tr><td></td><td>Energy in some form is a resource</td></tr>
<tr><td></td><td>Force dynamic elaboration of resource schema</td></tr>
<tr><td></td><td>Energy state as amount of substance</td></tr>
<tr><td></td><td>Energy as object located/moving on linear scale</td></tr>
<tr><td></td><td>Energy construed in terms of part-whole schema</td></tr>
</table>

experiential nature of the construals that seem to ground much of scientific understanding of the concept, motivates a hypothesis regarding the nature of the continuity between lay and scientific understanding of energy. Moreover, identifying experiential knowledge gestalts as construals implicit in scientific language, suggests that scientific discourse itself provides the learner with initial clues to constructing an understanding of the scientific concept in terms of conceptual resources already available to the learner" (Amin 2009, p.175).

3.2 Continuum Physics

Continuum physics (Treusdell and Toupin 1960; Treusdell and Noll 1965; Eringen 1971) leads to a unified approach to macroscopic processes that use the same few basic steps for conceptualization of different types of phenomena in the fields of fluids, electromagnetism, thermal phenomena, chemical substances, linear and rotational motion and gravity. From the perspective of conceptual metaphor theory, a coherent and uniform picture emerges, where the same image-schemas are employed in the different fields.

Every field provides a specific fundamental (extensive) fluid-like quantity (volume, charge, entropy, amount of substance, momentum and angular momentum, and gravitational mass, respectively) with a conjugated intensity or potential (pressure, electric potential, temperature, chemical potential, velocity and angular velocity, and gravitational potential, respectively). A shared set of metaphors structures the fields, making analogical thinking possible: VOLUME/CHARGE/ENTROPY/ETC. IS A FLUID- LIKE SUBSTANCE, PRESSURE/ELECTRIC POTENTIAL/TEMPERATURE/ETC. IS A VERTICAL SCALE. A fluid-like quantity can be thought of as residing in a delimited space whose geometrical and physical characteristics determine the intensity or potential. So, another transversal set of metaphors works: CYLINDERS/CAPACITORS/BODIES/ETC. ARE CONTAINERS OF FLUID VOLUME/CHARGE/ENTROPY/ETC. From a region of space, a fluid-like quantity can flow (conductive current) down the gradient of its own potential, limited by the resistance of the traversed material, or can be transported by a fluid (convective current), or by radiation (source current). Metaphors suitable to these cases are PIPES/ELECTRIC WIRES/CONDUCTORS/ETC. ARE PATHS FOR FLUID VOLUME/CHARGE/ENTROPY/ETC., FLUIDS ARE MOVING CONTAINERS FOR ENTROPY, GRAVITATIONAL/ELECTRIC/MAGNETIC FIELDS ARE SOURCE OF MOMENTUM and so on. Some of these fluid-like quantities are conserved (their amount in an insulated system does not change over time), others are not (can be created and destroyed)—entropy, in particular, can only be created but not destroyed.

Equations of balance of the fluid-like quantities make use of metaphoric projections of the image-schemas of *fluid-like substance*, *amount*, *container*, *surface*, *in–out*, *path*, *collection*, and *flow*. The visualization of these schemas (visual metaphors) is sketched in Fig. 1. The (visual) metaphors of the constitutive relations describing the conductive current densities of fluid-like quantities are depicted in Fig. 2.

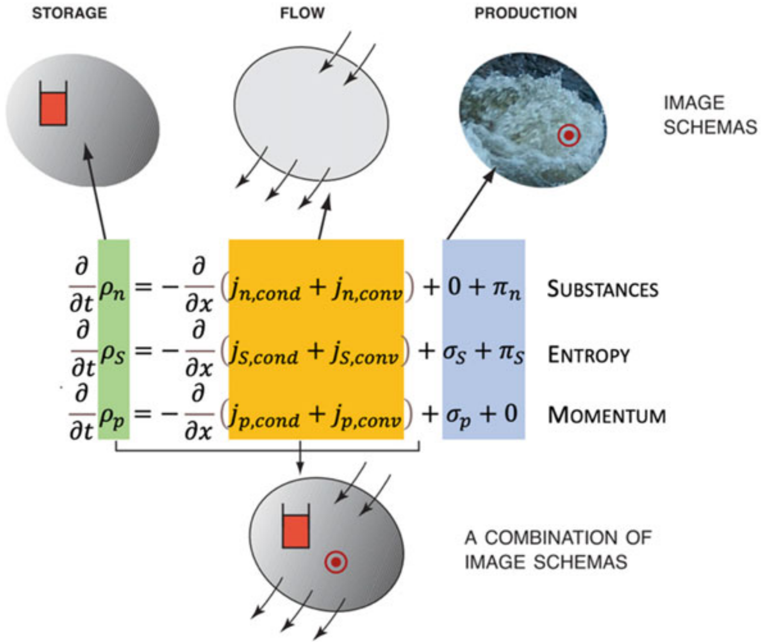


Fig. 1 Visual conceptual metaphors in the equation of balance for substances, entropy, and momentum. The spatial density of the fluid-like substances increases or decreases according to the balance of the conduction and convection currents, and the source and the production rates. Merged from Fuchs (2013), Corni et al. (2019)

Energy is a transversal (conceptual) quantity making it possible or regulating the interactions between the fundamental fluid-like quantities. Energy can be made available and used (when fluid-like quantities flow from higher to lower or lower to higher potentials), can flow carried by or can be stored in a fundamental fluid-like quantity. There is no “pure energy”, but there is always a fluid-like quantity having and carrying along energy.

For its structure based on primary metaphors, the continuum physics paradigm lends itself to an effective didactic practice suitable for primary to secondary school and university students. Among others, the advantages of such a coherent paradigm are the opportunity of extensively using analogical thinking and embodied activities and plays to metaphorically understand concepts (Fuchs et al. 2021; Scherr et al. 2012, 2013; Daane et al. 2014).

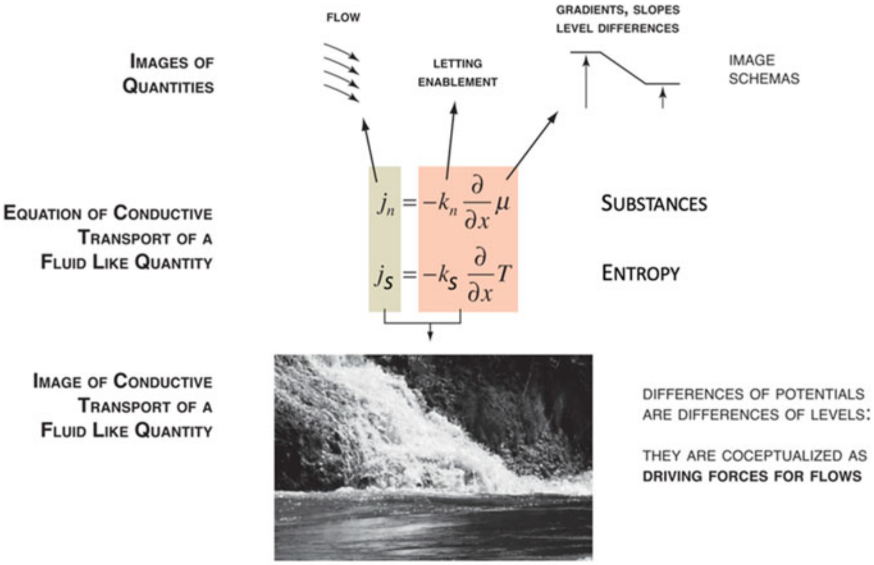


Fig. 2 Visual conceptual metaphors in the relationship between current and the gradient of the potential for substances and entropy. From Fuchs (2013)

4 Examples of Research Projects in Student Teacher Education in Physics

In the following sections, two projects conducted under my supervision will be synthetically summarized.

4.1 *The PPSE—Primary Physical Science Education Project*

In 2019, the Free University of Bozen-Bolzano has financed the 2-year project “PPSE—Primary Physical Science Education. Courses and materials for teacher education based upon an imaginative (metaphoric and narrative) approach to the experience of Forces of Nature”. The project has collected and further developed thought, research and experimentation conducted at the University of Modena and Reggio Emilia since 2010 and at the Free University of Bozen-Bolzano since 2014 under my supervision, in collaboration with several scholars, primarily Hans U. Fuchs from the Zurich University of Applied Sciences at Winterthur. The PPSE project laid the foundations for applying cognitive tools created by imagination to explorations of nature and the learning of natural science. Metaphor and narrative are among these tools that develop early in the life of a child; knowing what they are and how to use them, allows teachers to design approaches to pedagogy related to the interaction of a child with nature and technical artifacts.

Ingredients for a curriculum based on conceptual metaphor theory are:

- introduction of student teachers to embodied mind and conceptual metaphor theory;
- present them the main image-schemas involved in physics, e.g. *fluid-like substance*, *verticality*, *force*, *container*, *path*, *obstacle*, etc.;
- give them several occasions in different contexts to challenge their metaphors so that they become confident with their figures of thought;
- help them in differentiating the metaphors in their language and mind;
- support them in analogical thinking;
- support them when they feel the need for a step toward formal language (using specific terms, icons, maps, graphs, modeling, and maths).

The result of the project, among other products, is the design of a physics course for kindergarten and primary school student teachers, drawing upon four existing frameworks (see Fig. 3) in physics, narratology, cognitive linguistics and a theory of the development of cognitive tools (Lakoff and Johnson 1980, 1999; Fuchs 2010, 2015; Johnson 1987; Treusdell and Toupin 1960; Treusdell and Noll 1965; Egan 1997, 1990, 1988; Caracciolo 2014).

The main features of the course will now be outlined, as well as some significant students' outcomes and reactions. Theoretical foundations of the course, its implementation and evaluation are summarized in Corni and Fuchs (2020, 2021).

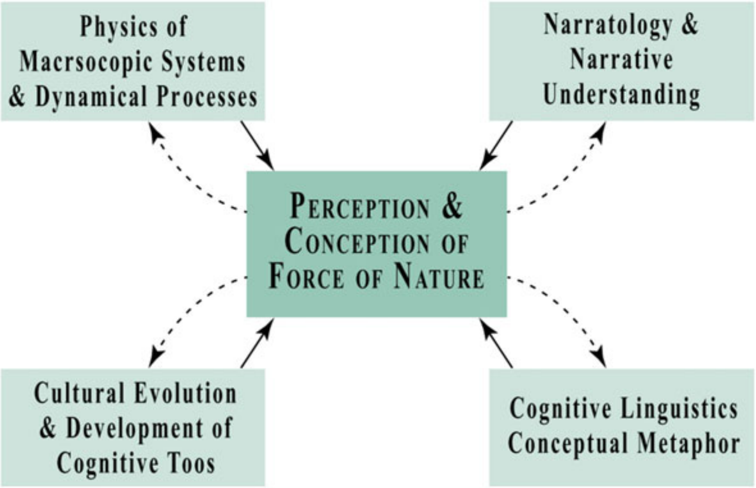


Fig. 3 The theoretical foundations of the course with metaphoric and narrative approach to the experience of Forces of Nature developed in the PPSE project. From Corni and Fuchs (2020)

Central to the course content are *Forces of nature* (water, wind, fire, ice, electricity, light, food, and many more), perceptual gestalts with aspects of quantity (corresponding to the image-schema of *fluid-like substance*), intensity (corresponding to *vertical scale*) and power (corresponding to *force*), that in macroscopic physics are categorized in a smaller set of *Fundamental Forces of Nature*, i.e. fluids, electricity and magnetism, heat, substance(s), linear and rotational motion, and gravity (see Sect. 3.2). The course identifies imaginative forms in physical science (e.g. the substance metaphor, the verticality metaphor, the container metaphor, etc.) and explicitly makes them available to student teachers as keywords for interpreting phenomena. It follows a bottom-up approach where scientific concepts grow upon the common figures of mind, instead of a top-down approach, where the start is from the formalized discipline adapted to student teachers and their pupils, careless of figures of mind. The focus is on the use of good natural language for describing and interpreting the phenomena of experience, with gradual development of formalization.

Table 2 shows the course contents and time allotted to subjects in lectures.

17% of the course hours (56 or 60 in total, according to the university site) are dedicated to topics not directly related to Physics. These hours are necessary for student teachers to correctly frame the disciplinary topics within the imaginative, metaphorical, and narrative approach. In fact, the discipline after the secondary instruction is viewed quite formally, with no relevance to experience in general and the didactic practice with children in particular. Moreover, in most cases, physics is perceived by student teachers as difficult, for which they do not feel inclined and experience a kind of aversion. Students' inclination toward the discipline after the course has been assessed in various ways, with positive results (Corni et al. 2014a, b; Fuchs 1997). The central part of the course (the remaining 83% of the hours) is dedicated to the execution of demonstration experiments about the Fundamental Forces of Nature. The interpretation of these experiments is in narrative form, practicing the use of primary conceptual metaphors in an increasingly formal language, from natural language,

Table 2 Course content and percentage of time allotted to subjects. From Corni and Fuchs (2021)

Lecture topic	% of time devoted to subject
Philosophical foundation	3
Linguistic tools: image-schemas and metaphors	4
The gestalt of Forces of Nature	4
Extensive and intensive physical quantities and constitutive relations	11
Analogical treatments of Forces of Nature	54
Energy	14
Cognitive tools in mythic and romantic understanding	5
How to build a story	5

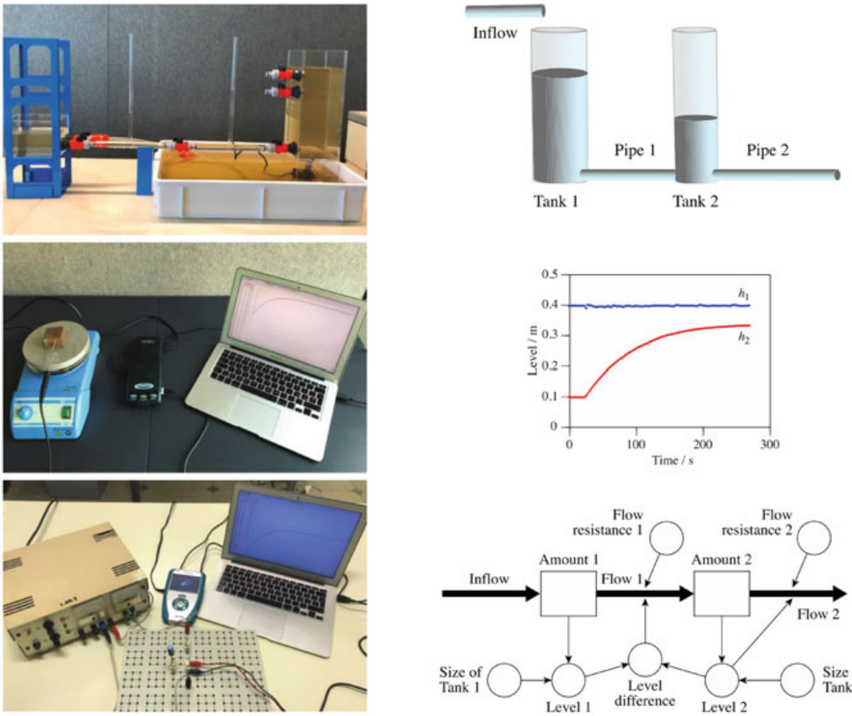


Fig. 4 Demonstration experiments with water, heat, and electricity with data collection and dynamic modeling (From Corni et al. 2019)

by means of stories and narratives, to visual formal language, by means of dynamic modeling with the Stock & Flow paradigm (see examples in Fig. 4).

Pieces of the narrative interpretation of a hydraulic experiment referring to the system in Fig. 4 top right, follows (the underlying primary metaphors are explicated in small caps in parentheses, and the capacitive, resistive-flow and balance laws are indicated in square brackets).

The water falling down is collected (WATER IS A FLUID-LIKE SUBSTANCE) into Tank 1 (TANKS ARE CONTAINERS) reaching a high level; this leads to a high hydraulic pressure (PRESSURE IS A VERTICAL SCALE) for the water at the bottom [capacitive law]. … Thanks to its intensity, the water is driven into Tank 2 (TANKS ARE CONTAINERS) allowed by the thin first pipe (PIPES ARE PATHS, PIPES ARE OBSTACLES) letting the second level rise quickly—the water in Tank 1 is powerful (WATER IS A FORCE) [resistive-flow law].

The water levels and, correspondingly, pressure levels, serve as driving forces for water flowing; if they are high (PRESSURE IS A VERTICAL SCALE), they can drive a strong current out (WATER IS A FLUID-LIKE SUBSTANCE). … If we keep the level of water in Tank 1 constant by continuously adding water (WATER IS A FLUID-LIKE SUBSTANCE), the rising level in Tank 2 leads to a lowering *of the level difference in the two Tanks, and consequently the lowering of pressure difference (*PRESSURE IS A VERTICAL SCALE*). This leads to a smaller driving force resulting in a weaker current (*WATER IS A FLUID-LIKE SUBSTANCE*). … The level in Tank 2 rises more and more slowly as time goes on. After some time, the level in Tank 2 also becomes constant; inflow and outflow balance and the amount of water (*WATER IS A FLUID-LIKE SUBSTANCE*) stays constant [balance law].*

The system dynamics model of the same process (Fig. 4 bottom right), obtained at the end of the language formalization path, is extensively discussed and referred to throughout the course. The model allows analogies and differences among the various Fundamental Forces of Nature to be highlighted. Figure 5 evidences the parts of the model related to the balance and the constitutive laws, acting as visual metaphors.

Energy is introduced employing the visual metaphor of substance recruited in the Perpetuum Mobile animated story (Deichmann 2014). In the story, the Fundamental Forces of Nature, represented as ghosts, make the machine work. In the visual metaphor of exchange proposed by the video, energy is made available when the potential of a Force of Nature falls down and is absorbed, with the contribution of a suitable device, by a second Force of Nature, whose potential rises up. Figure 6 shows some photograms of the video.

A step toward formalization is made with the introduction of *Process Diagrams*, visual metaphors of energy exchanges in natural or technical systems. Figure 7 (left) shows the process diagram of a water powerplant, where water current flows down (red arrow line on the left), releases the energy (green thick downward arrow) that is used in part to raise the potential of electric charge (bottom right red arrow line), and in part to produce entropy (top right red arrow).

Results of student teachers' disciplinary learning, didactic abilities, and inclination towards physics have been presented at various conferences (GIREP, ESERA, WCPE) and published in scientific journals in the last decade (Corni et al. 2014a, b, 2019; Corni and Dozza 2021; Landini et al. 2019). Student teachers reacted positively to the course: they reached good levels of learning, gave the course good evaluations, and were strongly engaged in and inclined toward sciences (tens of teacher students did their master theses in science education, despite their humanistic background). Another significant outcome is the in-service teachers' acceptance of the approach offered in training courses in the provinces of Modena, since 2010, with 30–50 teachers per year, and of Bolzano, since 2017, and their eagerness to continue working in this direction.

At the beginning of 2020, 14 in-service teachers, former students in the past 3–7 years, answered a questionnaire about their experience after the course. Here, we report the questions posed and the teacher results.

1. *How do you feel about science and science teaching (weak, secure, autonomous…)?*

   The great majority of the teachers (86%) feel (mostly) confident and/or autonomous in teaching science. Most of them are aware of their need for further training and study.

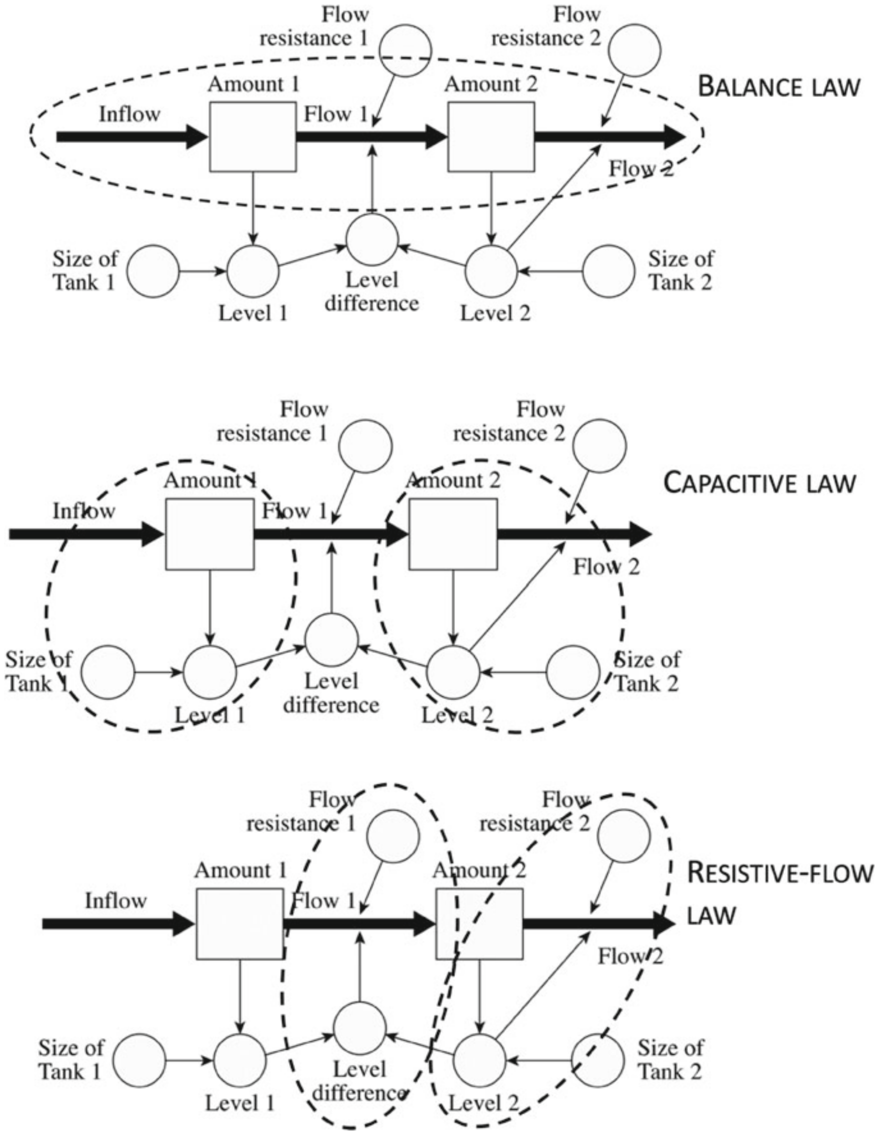


Fig. 5 Visual metaphors of balance and constitutive laws in the system dynamics model of the process depicted in Fig. 4 top right

2. *To what extent and in what way do you feel helped by the approach taken in the PPSE course?*

Almost all the teachers declare that they adopt the approach of the course in their own teaching. In some cases, they explicitly express great satisfaction and that the course shapes their teaching. The course opens up a fresh and effective way

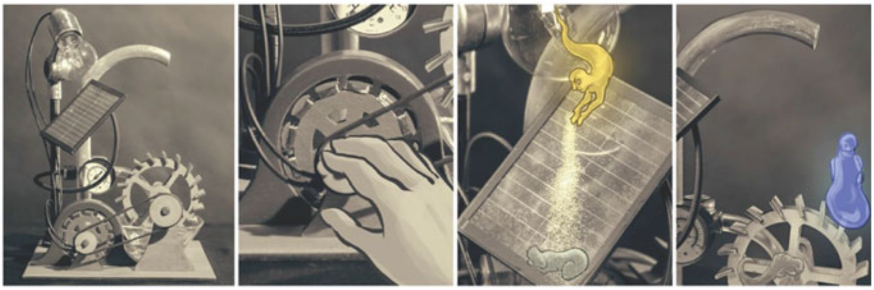


Fig. 6 Photograms of the Perpetuum Mobile animated story (Deichmann 2014) to introduce energy with the substance metaphor

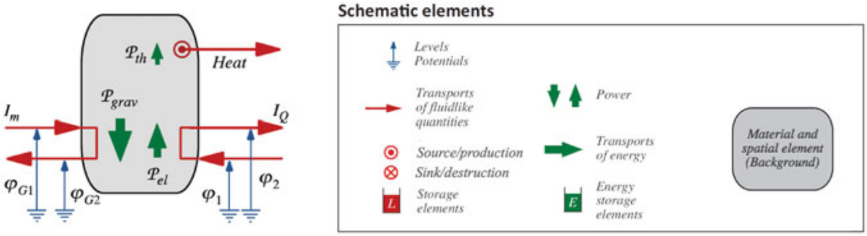


Fig. 7 (Left) Process diagram of a water powerplant. (Right) Symbol conventions in process diagrams

of teaching science including simple and concrete themes and tools. In particular, the course gives the teachers a methodology for observing and understanding their pupils' learning.

3. *Which elements of the course have shaped your teaching—not just of science—in the most profound ways?*

The most frequent course features teachers have become aware of as important for their teaching are the use of stories, metaphors, and analogies. 36% of respondents say that the linguistic tools have become central elements of their overall approach to teaching. They frequently use experimental work in teams where the syllabus asks for frontal lessons, and they note that they have learned to be able to listen to their pupils. Again, 36% of the teachers say that the PPSE approach provides them with an integrating point of view for the various disciplines and activities in their teaching.

4.2 Fundamental Conceptual Metaphors in Electric Circuits

Electricity is a highly abstract topic and metaphoric language is unavoidable. We studied to what extent in this topic metaphor is learnt by student teachers, how critically they use it, and what is their attitude toward it (Corni et al. 2022; Corni and Michelini 2022). The intervention involved 120 student teachers of the third year of the Master Degree in Education of the University of Udine in Italy in the academic year 2019–20 and consisted in a 2-h introductive seminar during the semester (treated topics: embodied cognition, conceptual metaphor theory, typical image-schemas used in physics), followed by lectures on electricity and electric circuits with no explicit mention to conceptual metaphor, and an end-of-topic questionnaire consisting of open-ended questions. Then, students have been engaged in the analysis of the metaphors in a selection of their own answers to the end-of-topic questionnaire. These expressions were chosen with consideration of the fact that they contained the primary conceptual metaphors we were most interested in (those related to image-schemas of *numerable* and *fluid-like substance*, and of *vertical scale* and *level*) and that lent themselves most easily to analysis by students. Some expressions were chosen because they were scientifically incorrect so that students could reformulate them. For every expression, students had to:

a. evidence the metaphor(s) behind the linguistic expressions in the answers;
b. suitably reformulate the expressions on the basis of their analysis;
c. motivate their choices;
d. answer metacognitive questions and write a comment in reaction to their experience with conceptual metaphor.

A table of the main image-schemas was made available to students to support them in their work.

We report here only two of the questions and the selected answers for the students' analysis in Table 3 and summarize the results of the analyses of these expressions made by 25 student teachers randomly chosen out of the 120 taking part to the intervention. See Corni et al. (2022) for the complete analysis.

Table 3 Examples of questions and selected answers for students' metaphoric analysis. The column on the right lists the image-schemas contained in the metaphorical expressions

Questions and answers	Image-schemas
1. I insert a switch in a battery-bulb circuit. I make myself small and enter the copper wire of the circuit. What do I see when the switch is open?	
1.1 If the switch is open, I can see the electrons stopping! They can no longer flow	Numerable substance, Fluid-like substance
1.2. The current does not flow because the circuit is interrupted	Fluid-like substance, path/cycle
2. What do I see in the connecting wire when the switch is closed?	
2.1 The current intensity passes through the whole circuit	Fluid-like substance, vertical scale/level
2.2 In the wire, the electrons move from one pole to another due to the difference of potential	Numerable substance, path/cycle, Vertical scale/level

Sample answer 1.1: If the switch is open, I can see the electrons stopping! they can no longer flow.

21 (84%) students detected both fluid-like and numerable substance metaphors, 3 (12%) students detected only one of the two.

17 (68%) students correctly rephrase the statement using only one metaphor (12 (48%) students use the fluid-like substance metaphor, 5 (20%) students use the numerable substance); 6 (24%) students rephrase using both metaphors.

20 (80%) students explicitly point out that, from a didactic point of view, only one metaphor is worth using in the same statement.

Sample answer 1.2: The current does not flow because the circuit is interrupted.

23 (92%) students detect the fluid-like substance metaphor, and 5 (36%) ones add the path/cycle metaphor.

20 (80%) students correctly rephrase the statement. 21 (84%) students use the fluid-like substance metaphor, 1 student uses the numerable substance metaphor.

14 (56%) students correctly motivate their reformulation, 3 (12%) give a wrong motivation.

4 (16%) students reiterate that only one metaphor must be used in the same statement.

Sample answer 2.1: The current intensity passes through the whole circuit.

20 (80%) students detect the vertical scale/level metaphor, 8 (32%) students detect the fluid-like substance metaphor, and 5 (20%) students detect the path/cycle metaphor.

23 (92%) students correctly rephrase the statement. 21 (84%) ones use the fluid-like substance metaphor, 6 (24%) ones add the vertical scale/level metaphor, 11 (44%) use the path/cycle metaphor.

24 (96%) students correctly motivate their reformulations: 16 (64%) of them explicitly point out that vertical scale/level and fluid-like substance metaphors must be differentiated.

Sample answer 2.2: In the wire, the electrons move from one pole to another due to the difference of potential.

19 (76%) students detect the vertical scale/level metaphor, 21 (84%) the numerable substance metaphor and 2 (8%) students detect the path/cycle metaphor.

20 (80%) students correctly rephrase the statement; 22 (88%) students use the numerable substance metaphor, 19 (76%) the vertical scale/ level metaphor and 6 (24%) the path/cycle metaphor.

17 (68%) students correctly motivate their reformulations, 3 (12%) do not explicitly motivate because they accept the statement as it is, and 4 (16%) students write wrong motivations.

Table 4 summarizes the average of correctly main primary metaphors detected by the students, calculated over the whole sample answers. The percentages are high in the three cases (and the standard deviations make them statistically indistinguishable), above all expectations, considering the short introduction on metaphor theory and metaphoric analysis (2-h seminar) the students had. From a professional point of

Table 4 Average of correctly detected main metaphors by the student teachers

Primary metaphor	Average correctly detected metaphors
ELECTRIC CHARGE IS A FLUID- LIKE SUBSTANCE	17.8 (s.d. = 5.6) 74% (s.d. = 23%)
ELECTRIC CHARGE IS A NUMERABLE SUBSTANCE	21 (s.d. = 2.4) 88% (s.d. = 10%)
ELECTRIC POTENTIAL IS A VERTICAL SCALE/LEVEL	20 (s.d. = 1.0) 83% (s.d. = 4%)

view, student teachers result capable to acquire and master the fundamental cognitive-linguistic skills offered by conceptual metaphor theory, and, from a disciplinary point of view, they are stimulated to effectively reflect on the discipline, becoming able to differentiate electric charge and current from electric potential and tension.

Finally, we report some of the most notable comments left by the student teachers in the metacognitive comments in reaction to their experience with conceptual metaphor.

Student 1. As a future teacher, [conceptual metaphor] is useful in order to learn to look at things "with the eyes" of our students. By being able to understand their structures and the way they interpret concepts, it is easier to understand how to fill in the gaps.

Student 2. In my opinion, this work helps towards a critical examination of one's own language, because every word can lead to a different image in the minds of children. If the terms used will not be correct, they could lead to a wrong construction of knowledge and therefore to serious conceptual errors (e.g. confusion is often made between charge and energy, between energy and substance).

Student 3. I think all teachers should do this analysis of themselves and their own disciplinary and non-disciplinary language.

5 Summary

In this paper, we have introduced conceptual metaphor theory and supplied examples of application in physics and examples of research projects in kindergarten and primary school student teacher education.

The drawn picture supports the thesis of conceptual metaphor as an approach to physics education suitable for student teachers.

Several are the disciplinary advantages it offers:

- it allows an elementary understanding of the fundamental concepts of the discipline;
- it offers a few schemas transversal to the discipline;
- it supports analogical thinking;

- it values the humanistic background of student teachers;
- it relies on (natural) languages (verbal, gestural, graphic…);
- it forms the basis for the development of formal scientific language.

At the same time, conceptual metaphor is a powerful professional tool in the hands of student teachers because:

- they become able to speak "naturally" about natural and technical phenomena;
- they can coherently use different kinds of language (verbal, gestural, graphic);
- they become sensitive to pupils' metaphors embedded in their language;
- they learn to listen to their pupils;
- they become able to see obstacles and progresses in their pupils;
- they are favored in evaluating their pupils' learning.

It must be made clear to student teachers that conceptual metaphors and image-schemas are not to be explicitly taught to their students in class. Rather, science and physics education in kindergarten and primary school should consist in giving children several different occasions of direct encounters with nature and technology and helping them to speak and explain their experiences in a good natural language. The teacher's role in the development of children' language (and mind) is to stimulate the challenge with their primary metaphors, taking care to learn a competent use and correct differentiation of the image-schemas. In other words, one of the fundamental goals of primary physics education, in parallel to the discovery of the world, is the appropriation and the mastering of the elementary figures of mind such as *container*, *substance*, *scale*, *force*, *cycle*, etc. which are at the root of scientific (human) thought. Teachers can also work backwards: becoming sensitive to detect the metaphors used by their pupils to communicate, they gain insight into children' conceptual development.

Amin (2009) suggests that "…the appropriation of construals implicit in language and the metaphorical nature of our understanding of many concepts pervasively reflected in language, together, are likely to constitute important sources of conceptual change". In an invited talk in 2014 in Reggio Emilia (Italy), he said: "The good news is that the multiple components that make up concepts can be seen as resources readily available to the learner. The bad news is that it becomes clear that learning a concept involves the challenging task of coordinating multiple knowledge elements".

In conclusion, we have gained evidence that conceptual metaphor is a powerful tool for student teachers, especially in the case of abstract topics such as electricity and energy. Student teachers take advantage of conceptual metaphors to analyze their own language and get a deeper and more critical insight into the disciplinary topics. This suggests that student teachers should be trained to perform metaphorical analysis, to consciously use the different metaphors of a given subject, and to master and to differentiate them.

Viewing science as a set of metaphors is not very different from thinking of science as a set of models, but with an emphasis on the discourse required to communicate these ideas. If we accept the basic tenet of metaphor theory, that all of our conceptual structures are metaphorical in nature, then our understanding of science also becomes a metaphor.

References

Amin TG (2009) Conceptual metaphor meets conceptual change. Hum Devel [Internet]. Cited 2014 Jan 12; 52(3):165–97. http://www.karger.com/doi/10.1159/000213891

Amin TG, Jeppsson F, Haglund J (2015) Conceptual metaphor and embodied cognition in science learning: introduction to special issue. In: Amin TG, Jeppsson F, Haglund J (eds) International journal of science education, vol 37, no 5–6, pp 745–58

Caracciolo M (2014) The experientiality of narrative. An enactivist approach. De Gruyter, Berlin

Corni F, Dozza L (2021) Max's worlds: an innovative project for K-6 science education. In: Jarosievitz B, Sükösd C (eds) Teaching-learning contemporary physics from research to practice [Internet]. Springer Nature Switzerland, Cham (CH), pp 237–49. https://link.springer.com/book/10.1007/978-3-030-78720-2

Corni F, Fuchs HU (2020) Primary physical science for student teachers at Kindergarten and primary school levels: Part I—Foundations of an imaginative approach to physical science. Interchange 51(3):315–343

Corni F, Fuchs HU (2021) Primary physical science for student teachers at Kindergarten and primary school levels: Part II—Implementation and evaluation of a course. Interchange [Internet] 52(2):203–236. https://rdcu.be/cfQHQ

Corni F, Fuchs HU, Dumont E (2019) Conceptual metaphor in physics education: roots of analogy, visual metaphors, and a primary physics course for student teachers. J Phys: Conf Ser 1286:012059

Corni F, Fuchs HU, Giliberti E, Mariani C (2014b) Primary school teachers: becoming aware of the relevance of their own scientific knowledge. In: Tasar MF (ed) Proceedings of the world conference on physics education 2012 [Internet]. Pegem Akademi, Ankara, pp 1063–1072. http://iupap-icpe.org/publications/proceedings/WCPE2012_proceedings.pdf

Corni F, Fuchs HU, Landini A, Giliberti E (2019) Visual and gestural metaphors for introducing energy to student teachers of primary school and kindergarten levels. J Phys Conf Ser [Internet] 1287:012043. https://iopscience.iop.org/article/10.1088/1742-6596/1287/1/012043

Corni F, Giliberti E, Fuchs HU (2014a) Student teachers writing science stories: a case study. In: Constantinou CP, Papadouris N, Hadjigeorgiou A (eds) ESERA 2013—Science education research for evidence-based teaching and coherence in learning, pp 2494–2505

Corni F, Michelini M (2022) Conceptual metaphor in teaching/learning electric circuits for student teachers of primary school and kindergarten. J Phys Conf Ser 2297

Corni F, Michelini M, Colletti L (2022) Training prospective primary and Kindergarten teachers on electric circuits using conceptual metaphors. Education Sciences [Internet], p 12. https://www.mdpi.com/2227-7102/12/7/457

Daane AR, Wells L, Scherr RE (2014) Energy theater. Phys Teach 52:291–294

Deichmann M (2014) Im ubertragenen Sinne. Metaphern und Bildvergleiche in der Wissernschaft [Internet]. Zurcher Hochschule der Kunste, Zurich. http://vimeo.com/98311515

Duit R (1987) Should energy be illustrated as something quasi-material? Int J Sci Educ 9(2):139–145

Egan K (1988) Primary understanding. Routledge, New York

Egan K (1990) Romantic understanding. The development of rationality and imagination. Routledge, New York

Egan K (1997) The educated mind. how cognitive tools shape our understanding [Internet]. The University of Chicago Press, Chicago. http://ebookcentral.proquest.com/lib/unibz/detail.action?docID=408518

Eringen AC (1971) Continuum physics. Academic Press, New York

Falk G, Herrmann F, Schmid GB (1983) Energy forms or energy carriers? Am J Phys [Internet] 51(12):1074–1077. http://aapt.scitation.org/doi/10.1119/1.13340

Fauconnier G, Turner M (2002) The way We think. Basic Books, New York

Feynman RP, Leighton RB, Sands M (1963). The Feynman lectures on physics. Vol. 1–3. Addison-Wesley, Reading

Fuchs HU (1997) The continuum physics paradigm in physics instruction II. System dynamics modeling of physical processes

Fuchs HU (2006) System dynamics in fluids, electricity, heat, and motion. examples, practical experience, and philosophy. In: Proceedings of the 2006 GIREP conference. University of Amsterdam, Amsterdam

Fuchs HU (2009) Figurative structures of thought in science

Fuchs HU (2010) The dynamics of heat, 2nd edn. Springer, New York

Fuchs HU (2015) From stories to scientific models and back: narrative framing in modern macroscopic physics. Int J Sci Educ 37(5–6):934–957

Fuchs HU (2014) The narrative structure of continuum thermodynamics. In: Constantinou CP, Papadouris N, Hadjigeorgiou A (eds) E-book proceedings of the ESERA 2013 conference: science education research for evidence-based teaching and coherence in learning. Part 1. European Science Education Research Association [Internet], Nicosia, Cyprus, pp 50–61. https://home.zhaw.ch/~fuh/MATERIALS/ESERA_2013_NSCT.pdf

Fuchs HU, Corni F, Pahl A (2021) Embodied simulations of forces of nature and the role of energy in physical systems. Educ Sci [Internet] 11(12):32. https://www.mdpi.com/2227-7102/11/12/759/htm

Gess-Newsome JA (2015) Model of teacher professional knowledge and skill including PCK: results of the thinking from the PCK summit. In: Berry A, Friedrichsen PJ, Loughran J (eds) Re-examining pedagogical content knowledge in science education. Routledge, London, pp 28–42

Gibbs RW (2005) Embodiment and cognitive science. Cambridge University Press, Cambridge UK

Hampe B (2005) From perception to meaning. image schemas in cognitive linguistics. Mouton de Gruyter, Berlin

Johnson M (1987) The body in the mind. University of Chicago Press, Chicago

Karal IS, Alev N (2016) Development of pre-service physics teachers' pedagogical content knowledge (PCK) throughout their initial training. Teach Devel 20(2):162–180

Kind V, Chan KKH (2019) Resolving the amalgam: connecting pedagogical content knowledge, content knowledge and pedagogical knowledge. Int J Sci Educ 41(7):964–978

Kulgemeyer C, Riese J (2018) From professional knowledge to professional performance: the impact of CK and PCK on teaching quality in explaining situations. J Res Sci Teach 55(10):1393–1418

Lakoff G (1987) Women, fire, and dangerous things. University of Chicago Press, Chicago Ill

Lakoff G (2014) Mapping the brain's metaphor circuitry: metaphorical thought in everyday reason. Front Hum Neurosci [Internet] 8(December):958. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=4267278&tool=pmcentrez&rendertype=abstract

Lakoff G, Johnson M (1980) Metaphors we live by. University of Chicago Press, Chicago

Lakoff G, Johnson M (1999) Philosophy in the flesh. Basic Books

Lakoff G, Nunez RE (2000) Where mathematics comes from [Internet]. Basic Books. https://archive.org/details/MathematicsLakof/mode/1up

Lancor R (2014) Using metaphor theory to examine conceptions of energy in biology, chemistry, and physics. Sci Educ 23(6):1245–1267

Lancor R (2015) An analysis of metaphors used by students to describe energy in an interdisciplinary general science course. Int J Sci Educ 37(5–6):876–902

Landini A, Giliberti E, Corni F (2019) The role of playing in the representation of the concept of energy: a lab experience for future primary school teachers. In: McLoughlin E, van Kampen P (eds) Concepts, strategies and models to enhance physics teaching and learning. Springer, pp 125–137

Park S, Oliver JS (2008) Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. Res Sci Educ 38(3):261–284

Reddy MJ (1979) The conduit metaphor: a case of frame conflict in our language about language. In: Ortony A (ed) Metaphor and thought. Cambridge University Press, Cambridge UK, pp 284–310

Scherr RE, Close HG, Close EW, Flood VJ, McKagan SB, Robertson AD et al (2013) Negotiating energy dynamics through embodied action in a materially structured environment. Phys Rev Spec Top—Phys Educ Res [Internet]. 2013 July [cited 2013, August 12]; 9(2):020105. http://link.aps.org/doi/10.1103/PhysRevSTPER.9.020105

Scherr RE, Close HG, McKagan SB, Vokos S (2012) Representing energy. I. Representing a substance ontology for energy. Phys Rev Spec Top—Phys Educ Res 8(2):1–11

Shulman LS (1986) Those who understand: knowledge growth in teaching. Educ Res [Internet] 15(2):4–14. http://edr.sagepub.com/cgi/doi/10.3102/0013189X015002004

Treusdell AC, Noll W (1965) The non-linear field theories of mechanics. In: Encyclopedia of physics, vol III/3. Springer

Treusdell AC, Toupin RA (1960) The classical field theories. In: Encyclopedia of physics, vol III/1. Springer

Watts DM (1983) Some alternative views of energy. Phys Educ 18(5):213–217

Young Children Interacting with the Physical World

Suzanne Gatt

Abstract Children start expressing an interest in how the world works as soon as they become aware of their surroundings. This is often demonstrated in their play, with curiosity leading them to experience, engage with and explore physical phenomena which adults usually take for granted. Many are those who tend to associate topics such as air, pressure, electricity, forces and other science topics with secondary students learning physics. Developments in primary science education, however, show that young children already possess ideas, even if many are alternative ideas, before starting school science. Children can, nonetheless, be supported to build on these ideas by giving them opportunities to inquire about physical phenomena around them to find out how they are affected by different factors and conditions. This chapter considers inquiry examples developed as part of the work by the EU-funded project Pri-Sci-Net to show how inquiry activities have been designed and implemented to promote better engagement with physics concepts among young children. It considers how children can, from the first years of schooling, start developing inquiry skills which are so important to learning physical sciences at higher levels.

1 Introduction

The natural world is a wonderful place (Zhang et al. 2022). The beauty and aesthetic value of the world's physical sites such as the Grand Canyon, the Niagara Falls, the Dolomites, the River Rhine, are just a few examples. They act as illustrations of the physical laws which govern the way that the world works as we view the snow on mountains, the water falling under the force of gravity in the Niagara Falls, and how weather conditions played a role in carving the many valleys around the world. Many of these beautiful sites, which result from physical phenomena, have been considered as priceless and irreplaceable assets at world level by UNESCO, attributing them not only to a particular nation but also to the whole of humanity (UNESCO 1972).

S. Gatt (✉)
Faculty of Education, University of Malta, Msida, Malta
e-mail: suzanne.gatt@um.edu.mt

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2023

J. Borg Marks and P. Galea (eds.), *Physics Teacher Education*,
Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-44312-1_2

Many are those who consider the natural world to refer mainly to living nature and biodiversity, such as jungles and tropical forests full of animals and plant biodiversity. Few would probably acknowledge the many physical phenomena such as the weather, wind, air pressure, movement, electricity, etc. that also form part of nature. Scientific laws and concepts such as the force of gravity, viscosity, states of matter, change of state, laws of motion are but a few of the physical concepts at play in shaping our physical world. These phenomena make up part of our environment and are everyday occurrences. They are what makes the world work in predictable ways. They represent the beautiful mathematical laws that govern the physical world, and which, while not directly evident, provide order to our world.

The world is an exciting place for young children to explore as they grow up. It provides them with rich opportunities to learn about the diversity of living and non-living things around them. Children also experience how physical phenomena respond to their actions (Lynneth et al. 2017). Like scientists, young children wonder about how their actions on the world always lead to the same result: why the keys always drop to the ground; how they hear a sound every time they bang their toy on the floor; and how their toy car moves faster and further when they push it harder. This is what often leads children to experiment and investigate, as they try different actions to see what happens. Children's interaction with physical phenomena is the means by which they inquire and gain more understanding about how the world they live in works.

Learning science forms part of children's core early years' learning curriculum in many countries across the world. It is believed that it helps them understand scientific concepts which are linked to their everyday experiences of natural phenomena (Harlen 2001). Children engage naturally with science as they ask questions and try things out to find answers (Rhodes et al. 2020; Ashbrook 2005). They often learn about and discover how physical principles work because of their play actions with objects (Lehn 1998). Learning really starts naturally from a very young age as children experience and inquire about the world around them because of their curiosity (Garvey 1990). Such explorations lead them to identify, understand and apply interconnections in the technological world (Meeteren and Zan 2010).

This chapter discusses how young children in the early years can access physics concepts, which are often considered too difficult and beyond their cognitive capabilities, through play or semi-structured inquiry activities. Examples are provided from insights obtained from a number of inquiry activities trialled in the Pri-Sci-Net project, which promoted inquiry-based learning among young children (Gatt and Armeni 2014). These activities illustrate how young children can carry out investigations and cognitively engage with physics concepts despite being only 5 years old or younger.

2 Theoretical Framework: Inquiry as the Driver for Learning About Physics Concepts

Children develop intuitive understandings of the physical world through specific everyday contexts prior to learning formal science at school (Arnold and Millar 1996). This is mainly a result of their direct experiences in the physical world (Fleer and Pramling 2014). Research during the 1980s and 1990s provided evidence of how children of all ages hold ideas about how the physical world works. The Primary SPACE (science processes and concept exploration) Project Research carried out in the early 1990s highlighted how even children as young as 5 years old held alternative ideas about physical phenomena such as evaporation and condensation (Terry and Watt 1990), light (Osborne et al. 1990a), rock soil and weather (Terry et al. 1990), the Earth (Osborne et al. 1990b), forces (Terry et al. 1998) and sound (Watt and Terry 1990).

The alternative ideas identified among children by these studies reflect common characteristics (Gatt 2003). They highlight how children often hold personal ideas (Driver et al. 1985), which are scientifically incorrect. There is some evidence that children can change their ideas through investigations, which provide results that differ from the ideas they held previously. However, alternative ideas remain unwavering among some children (Papandreou and Kalaitzidou 2019). Young students can usually discuss phenomena which they experience and can see. Nonetheless, some of the children's responses are quite original and reflect a degree of logic in their reasoning. One common feature among young children is that of attributing animistic and anthropomorphic properties (Driver 1985).

Many science educators have tried to explore and develop means to support conceptual understanding among young students in the early years and at primary school level. There is acknowledgement that understanding children's ideas about natural phenomena is crucial to learning science, as this informal knowledge serves (even if this is not necessarily correct science) as a starting point for planning science activities, which are responsive to the needs of young learners (Papandreou and Kalaitzidou 2019; Ergazaki et al. 2010; Papandreou and Terzi 2011).

Inquiry-based learning (IBL) in science is not a new pedagogical approach but has been around for a good number of years. Inquiry can be traced back to Dewey, who argued that learning science should build on previous experiences and through direct material interaction in both a social and physical environment, and leading to reflection (Dewey 1897, 1938). He highlighted the value of practical problem-solving activities and real-world situations, which are mind-stimulating and promote effective learning (Dewey 1916). All these aspects form the basis of inquiry-based learning.

Inquiry-based learning was strongly encouraged in the U.S. in 1995, with its focus on inquiry as the main pedagogy for learning science in its published National Science Education Standards. Inquiry-based learning was expected to act as the main vehicle which would make scientific literacy for all a reality in the twenty-first century (National Research Council 2000). The term 'Inquiry' was considered to refer to:

students' ability to ask questions which can be answered by investigating, designing and carrying out scientific investigations where data are collected and then used to propose answers to the question set. The main argument was that inquiry facilitated children's understanding of the nature of a scientific inquiry and processes, with the realisation that results from investigations are never straightforward. Of course, besides the process and nature of science, inquiry is also a pedagogy that involves teaching and learning strategies that lead to the learning of scientific concepts. The U.S. Standards, based on inquiry, thus drew connections between learning science, learning to do science and learning about science (National Research Council 2000).

The U.S. guidelines (National Research Council 2000) identified the skills and competences in science that young children can develop through inquiry. They indicated that children can learn to ask questions about objects, organisms and events in the environment; and that these questions can be answered when children apply their scientific knowledge to the observations gathered during investigations. As children design and plan simple investigations, mainly based on simple observations, they search for answers to the questions that they set, as well as test ideas brought forward by others. Children, through carrying out investigations, also learn how to use scientific equipment, even if these are simple instruments like rulers, thermometers, and stop-watches. Children, thus, learn how to measure, cut, connect, switch, turn on and off, pour, hold, tie, and hook. They learn how rulers measure length, height and depth of objects and materials; thermometers measure temperature; watches measure time; beam balances and spring scales measure weight and force; and magnifying glasses are used to observe objects in greater detail. Children also develop skills in the use of computers and other technologies to conduct investigations, with inquiry becoming more complex in higher levels of primary education.

Carrying out an investigation in response to an inquiry question is just part of the process of scientific inquiry. The main purpose of investigations is for learners to use the data collected to construct a reasonable explanation in response to the original question set. Some science educators consider these data as sources of evidence, which are then reflected upon and used to articulate arguments in support of conclusions drawn (Gatt and Armeni 2014). The value of data collected is also emphasised with respect to the importance for students to think and reflect while they manipulate the data collected and formulate possible explanations. Even young children should have the opportunity to learn about what constitutes as evidence in an investigation and be given the chance to judge the strength and limitations of conclusions drawn by also considering the source of information and its robustness (National Research Council 2000).

Inquiry goes beyond drawing conclusions and proposing explanations, as children are expected to use their knowledge and the evidence that they obtained to support their explanations when these are questioned and rebutted by their teachers and peers. One role of teachers is to help children learn how to check their explanations against scientific knowledge, experiences, and scrutiny by others (National Research Council 2000). Communication forms another integral part of the inquiry process, as it requires students to share their results and conclusions made. Students, thus, also develop the ability to communicate, critique and analyse their work and the work of other students. This communication might be expressed in spoken, visual, as well as in written format (National Research Council 2000).

Learning through inquiry-based learning helps students develop inquiry skills alongside the understanding of scientific concepts. Inquiry is a pedagogy that allows different approaches to be adopted. For example, inquiry can start with a question or a problem to be solved. However, whatever approach educators take, all types of inquiry involve children engaged in active learning. Inquiry is also a social activity with children working in groups as they carry out investigations and together figuring out meanings and explanations for their observations. Such group talk promotes the social construction of knowledge (Russell and McGuigan 2016), which leads to learning. Inquiry thus provides the context through the question and allows the collection of evidence through the observations made during investigations. It promotes learning through the social construction of knowledge as children engage in the inquiry process physically, mentally and socially to different degrees, but with the result of ensuring effective learning and an understanding of what it means and feels to do science.

Inquiry among young children is different to the types of inquiry, which takes place in the upper-primary years and secondary-level science. One finds less structure and formality in early years' practices, with play as a common occurrence in such settings. Children have the opportunity to learn about the physical world as they engage in their play activity. Such informal approaches may, at face value, seem like just play and not much more. Play activities, however, may promote deep engagement in inquiry, as children show self-direction when they choose what they play and how they play; explore for themselves and select objects or activities based on their own interests; enjoy what they are doing; and that there is no end goal or specific correct response. Such experiences may look very different from the structured laboratory experiments that scientists carry out. However, they still reflect key scientific processes that scientists apply, even if at a much simpler level. Thus, doing science with young children is about encouraging imagination, creativity and curiosity while also nurturing key scientific skills to form a firm base for future learning (Gatt and Vella 2003). It also preserves the importance of following children's interests and keeping science as an activity where there is effective learning and which children enjoy.

3 Practical Examples of Children's Inquiry of the Physical World

It is one thing to promote particular practices. It is, on the other hand, totally different to actually manage to implement what one preaches. Pri-Sci-Net,[1] an EU-funded project, focused on children at primary level. It defined inquiry-based learning at primary level as a framework which targets the three different aspects of science: learning science (content); learning how to do science (process) and learning about science (nature of science). Children, in such an approach, learn science (and physics concepts) by considering authentic situations that children encounter in their everyday lives. Inquiry can also include problems that are presented to the children, who then carry out investigations and make observations as part of an evidence-collecting process. These investigations serve to promote the process of science: they develop the skills of systematic observation, questioning, planning and recording to obtain this evidence. They also involve collaborative group work, where children interact in a social setting and construct knowledge through discursive argumentation. The children are encouraged to communicate with others as the main process of learning. The Pri-Sci-Net vision also aims to support children to develop autonomy and self-regulation through these inquiry activities as they take responsibility of their learning and work through the complete inquiry cycle, from the questions set to the presentation of the final conclusions based on evidence.

The teacher has a specific role in this type of inquiry, in scaffolding and guiding the students' learning by acting as a role model of an inquiring learner. The teacher, thus, is not considered as the holder of expert knowledge. The main role of the teacher is, rather, to facilitate the students' negotiation of ideas and to highlight criteria for formulating classroom knowledge. Key steps in an inquiry activity for young children are considered to involve: the engagement phase, which introduces the topic and the inquiry question; the inquiry phase, which involves the children carrying out the investigation; and the evaluation phase where the evidence collected is used, like evidence, to reach an answer or answers in response to the original inquiry question set.

A total of 45 activities, 15 for children aged 3–5 years (Gatt 2014a), 15 for children aged 6–8 years (Gatt 2014b), and 15 for children aged 9–11 years (Gatt 2014c) were developed. In this chapter, only examples of activities which were designed for the younger groups will be considered, as some have been implemented and evaluated in schools in Malta.

Three activities were considered and trialled in four classrooms in two local primary schools. All three activities targeted physics concepts, namely, magnets and their magnetic properties, buoyancy (by tackling floating and sinking) and the centre of gravity and stability when building strong and stable walls.

---

[1] The project Pri-Sci-Net has received funding from the European Union Seventh Framework Programme (FP7 2007 /13) under grant agreement No.266647. The project focused on promoting inquiry-based learning approaches at primary level of education with children from age 3-11 years across Europe.

How can we find the magnet? (Constantinou et al.): Children in groups of 4–5 were given a box with five wrapped objects, including a magnet. They were then asked to find out which wrapped present contained the magnet without removing the wrappings. The children were then asked to present what they did and give instructions to the teacher to help her identify a magnet. At the end of the activity, the children, under the guidance of the teacher, formulated an operational definition of a magnet and the procedure they used to distinguish the wrapped magnets from other objects.

Let's Float (Keere 2014): Children were first allowed to experience the notion of floating and sinking. They tried different objects to answer the question: 'Which ones float and which ones sink?' After this exploration phase, the children were given a little box and asked how many marbles they could add and keep the box afloat.

Strong Walls (Mestagh 2014): Children were asked to investigate different wall designs and the impact of their design on the wall's strength. They were given a number of bricks and challenged to build the strongest possible wall. They were then invited to test their walls' strength by means of a slide and a toy car. This inquiry activity involved fair testing where the children needed to keep a number of factors constant to compare the strength of the different walls' design.

The methodology for evaluating the effectiveness in engaging children in inquiry involved finding teachers in schools to try out the three activities with their class students. Each activity implemented was observed and field notes of the observations were written up. At the end of the activities, the teachers were interviewed by the author as the researcher. In addition, informal conversations with the children about what they did were held to collect the children's voices. Prior to the data collection, ethical clearance was obtained from the University of Malta, and all the required permissions to access the schools and classes were obtained. Signed consent to take part in the project was obtained from the children's parents and teachers. Assent from the children was obtained with the support of the teacher who explained the researcher's role in wishing to find out whether or not the children liked the activities. The magnets' activity was trialled with one preschool class (4 years) and a first primary class (5 years); the floating activity was trialled with one reception year (3 years); and the strong walls were used with a first-year primary class (5 years). The two schools involved were one boys' school and one co-ed school.

4 The Impact of Inquiry-Based Learning with Young Children

Interesting insights were obtained from the observations made and the teachers' and students' contributions. The different activities showed how the children of different ages could inquire and engage with the activities at different levels, reflecting both age differences, as well as different cognitive levels. The key takeaways are presented below with illustrations from the different activities.

Activities become meaningful when they are authentic: This was significantly evident when the activities were implemented with the younger children. When the magnets' activity was carried out with the preschool class who were 4 years old, they were not sure what magnets were. It was only when the teacher suggested that they were like the fridge magnet that the children realised what the magnet is and what its properties are. In fact, as soon as they realised what the magnet was, they all ran together to place the wrapped presents in contact with the metal cupboard and identified the magnet because it was the one which stuck. This instance shows how important it is for activities to be authentic and represent contexts which children are familiar with. The children did not immediately identify what a magnet was, as they had probably never handled one before. On the other hand, many are those families who have fridge magnets at home. As soon as the children associated the activity with their familiar home environment, they could conduct the inquiry very easily. This showed that it is very difficult to conduct inquiry if the context is not familiar to the children.

Children engaged at different cognitive levels in the same activity: The magnets' activity was also conducted with a first-year primary class of boys. This class was used to carrying out inquiry activities as their teacher liked to teach science through inquiry. Having presented the boys with the problem, she asked them to help her identify which wrapped present contained the magnet. She distributed a box with various wrapped presents to each of the four groups of students. All the groups managed to identify which wrapping contained the magnet. One group of students reached their conclusion by comparing their observations. They first noticed all those which attracted each other. This reduced the presence from five to three (one magnet and two metal objects stuck together). They then found which one was the magnet by noting which present from these three stuck to both of the other two presents (magnet attracting the two metals), while the other two were eliminated as they only attracted one (the magnet but not the metal). Considering that these children were only 5 years old highlights how, despite their limited level of cognitive development, they could still arrive at identifying the present containing the magnet through deduction. Lower levels of cognitive thinking were observed by the other two groups of children, even if they still managed to identify the wrapped present containing the magnet. These children knew that magnets are attracted to metal. They thus looked around them in class to identify which furniture was made of metal, e.g., the legs of their chairs, and placed all the presents next to the metal. The present which stuck to the metal chairs' legs was identified as the magnet. The last group, on the other hand, struggled to understand what a magnet was and it was only after an explanation by the teacher that they managed to carry out the simple investigation. This inquiry activity showed how an activity can achieve differentiation, allowing children to inquire at a level according to their cognitive level and scientific knowledge.

Children could identify and design a fair test: This was evident in the case of the first-year boys in primary when discussing ways on how to test the strength of the walls which they built. Having built their walls, the children discussed with their teacher how they could best test each wall in a way to see which one was the strongest. The children first highlighted how important it was for each group to build their wall from the exact number of identical bricks, as otherwise, it would not be fair. When the teacher introduced the ramp with the car, they easily pointed out that it was better if the car was let go rather than pushed, as it was difficult to say if the push was the same. They also were very careful to always put the wall at the same distance away from the ramp. Discussions demonstrated that not only did the children have a conception of a fair test but that they could also design one that would ensure that all the factors were kept equal and to deduce that the outcome would only be due to the design of the wall that they built. Interestingly, they also requested that the measure of how much the wall moved backwards was to be repeated for accuracy, for exactly the same purposes that scientists take repeated readings when taking measurements in scientific experiments.

Younger children do not always engage in inquiry directly, but may still be aware of the physics concepts involved: One interesting observation was obtained from watching the floating and sinking activity. This was carried out with the youngest group of children—the 3-year-olds. There is a great difference in terms of participation and self-expression between 3 and 4-year-old children. It is very difficult to have some structure when working with 3-year-olds and, in many cases, the children's vocabulary is restricted. In the case of the floating activity, the teacher filled a large container with water and invited the children standing around it to throw things in it to see what happens. Many of the children wondered how 'some things went to the bottom of the bath while others stayed up.' The teacher realised that many of them did not yet know the terms 'float' and 'sink' and took this opportunity to introduce these new words through her conversations with the children. She then proceeded to do the second step of the activity, and under supervision, asked the children how many marbles they could put inside the containers floating on the water and count them. It took some time for the children to realise what was happening. Since the container used in this activity was large in size, some children preferred to just play with the water and did not carry out the inquiry presented. They engaged in role-play instead, pretending they were washing the plates. So, the teacher took three smaller basins and filled them with water and invited the children to continue with their play in the basin. It is here that one observation demonstrated how even 3-year-olds inquire in their own informal way. One girl who was playing with her tea set took one plastic cup and placed it on the water. She noted that it floated. She then started slowly putting more toys inside the cup, as it continued to float without sinking. This showed how the girl, even if not verbally acknowledging the floating activity where they used marbles to put into containers while they floated, had still gained insight into the physical concept of floating and sinking, realising that a floating object can continue to float if you load it slowly, until it can hold no more. While it is obvious that young children are not able to understand the exact physics of what was happening, and even less to explain it verbally, they can still engage meaningfully with physical phenomena and gain insights about how the physical world works within their capacity.

5 Discussion

The observations outlined in the previous section provide some evidence of the potential of doing inquiry with young children. They show that it is possible for children to have meaningful interactions with the physical world. While children may not fully understand the physics relationships at play, inquiry experiences can serve to set the foundations for better learning and understanding of physics when the children grow up. Inquiry also nurtures children's curiosity and their willingness to test things out for themselves, as they develop inquiry skills. Talking with the children about the activities that they were doing was an interesting eye-opener, as in the case of the Year 1 boys who always greeted me eagerly during my visits and excitedly told me about their experiments and what they thought would happen, how they tested things and what they found out, providing explanations for their observations.

Young children never cease to surprise adults (Biermeier 2015). It is amazing how much they can understand what is happening and why it happens. It is for this reason that I make a strong argument in favour of young children's ability to inquire as they explore physical phenomena (Keifert and Stevens 2019). Even if the process is less formal, as demonstrated by these children, they were still able to demonstrate instances of scientific insights (Tullos and Woolley 2009).

Science was and remains important as the world becomes even more technological (Aikenhead 1994). It is the vehicle that keeps children close to the physical world within a more prominent virtual reality. Inquiring about the physical world is key, not only to learning about the physical world around us but also promotes habits of mind, which makes persons less gullible to fake news and media manipulation (Bryanov and Vziatysheva 2021). One advantage of working with young children is that they are still free and not yet influenced by schooling with its imposition on the way we think (Amabile et al. 1986). It is much easier to nurture young children's curiosity and motivation to learn about the world around them. So far, initiatives by teachers have shown how young children demonstrate higher levels of cognitive engagement when inquiring about how physical phenomena work (Cian et al. 2018). It is then important to start them young, building on their existing curiosity to develop a mindset which asks, tests and evaluates the evidence available. The main challenge has been and remains that of changing the system of education into one which promotes more curiosity, inquiry, investigation and independent thinking among children (Jirout 2020).

6 Conclusion

This chapter has presented a strong argument on how young children not only innately inquire about and investigate the physical world around them but are also able to gain insights into how the world works in much greater depth than some adults would expect. If one is able to overlook the literacy and oral limitations of children to express themselves and instead observe closely how children try things out, we can understand which approaches work best to help young children's learning. Teachers and schools could maximise the learning opportunities available to young children whereby they can follow their children's interests and ensure that more meaningful learning takes place. Such an approach may also finally bring a shift in how students learn about physics concepts, not only within the early years through an informal accumulation of knowledge but also across the rest of compulsory education. This would give us hope that future generations will produce more and better scientists, as well as conscientious and better citizens who are both scientifically literate as well as possess the skills to distinguish between fake manipulative messages and evidence-based statements. It is for this reason that we need more inquiring minds and to support inquiries from as early an age as possible.

Notes

- The author was the coordinator of the Pri-Sci-Net project with 16 partners from 14 different European countries. The project Pri-Sci-Net has received funding from the European Union Seventh Framework Programme (FP7 2007/13) under grant agreement Number 266647.

References

Aikenhead G (1994) What is STS science teaching STS education. Int Perspect Reform 2(12):47–59

Amabile TM, Hennessey BA, Grossman BS (1986) Social influences on creativity: the effects of contracted-for reward. J Pers Soc Psychol 50(1):14–23. https://doi.org/10.1037/0022-3514.50.1.14

Arnold M, Millar R (1996) Exploring the use of analogies in the teaching of heat temperature and thermal equilibrium. In: Welford G, Osborne J, Scott P (eds) Research in science education in Europe. The Falmer Press, London, chapter 2, pp 219–229

Ashbrook P (2005) The early years: what can young children do as scientists. Sci Child 43(1):24–27

Biermeier MA (2015) Inspired by Reggio Emilia: emergent curriculum in relationship-driven learning environments. Young Child 70(5)

Bryanov K, Vziatysheva V (2021) Determinants of individuals' belief in fake news: a scoping review determinants of belief in fake news. PLoS ONE 16:6. https://doi.org/10.1371/journal.pone.0253717

Cian H, Marshall J, Qian M (2018) Inquiry classroom patterns of student cognitive engagement: an analysis using growth curve modeling. J Sci Teach Educ 29(4):326–346. https://doi.org/10.1080/1046560X.2018.1456884

Constantinou CP, Feronymou G, Kyriakidou E et al. How can we find the magnet? Inquiry-based activities for primary children: 3–5 years. In: Gatt S (ed). Malta Council for Science and Technology, Malta, pp 42–44

Dewey J (1897) My pedagogic creed. School J LIV 3, 77–80

Dewey J (1916) Democracy and education: an introduction to the philosophy of education. MacMillan, New York

Dewey J (1938) Experience and education. Kappa Delta Pi, United States of America

Driver R (1985) Introduction. In: Driver R, Guense E, Tiberghein E (ed) Children's ideas in science. Open University Press, Milton Keynes

Driver R, Guense E, Tiberghein A (1985) Children's ideas in science. Open University Press, Milton Keynes

Ergazaki M, Saltapida K, Zogza V (2010) From young children's ideas about germs to ideas shaping a learning environment. Res Sci Educ 40(5):699–715. https://doi.org/10.1007/s11165-009-9140-2

Fleer M, Pramling NA (2014) Cultural-historical study of children learning science: foregrounding affective imagination in play-based settings. Springer, Dordrecht

Garvey C (1990) Play. Harvard University Press, Cambridge, MA

Gatt S (2003) Helping young children understand science concepts. In: Gatt S, Vella Y (eds) Constructivist teaching in primary school: examples in social studies, science, mathematics, design and technology and ICT. Agenda Publishers, Malta, chapter 2

Gatt S (ed) (2014a) Inquiry-based activities for primary children: 3–5 years. Malta Council for Science and Technology, Malta

Gatt S (ed) (2014b) Inquiry-based activities for primary children: 6–8 years. Malta Council for Science and Technology, Malta

Gatt S (ed) (2014c) Inquiry-based activities for primary children: 9–11 years. Malta Council for Science and Technology, Malta

Gatt S, Armeni L (2014) Pri-Sci-Net—a project promoting inquiry-based learning in primary science: experiences of young children inquiring. Lit Inf Comput Educ J (LICEJ) 5(2):1582–1587

Gatt S, Vella Y (2003) Constructivist teaching in primary school: examples in social studies, science, mathematics, design and technology and ICT. Agenda Publishers, Malta

Harlen W (2001) Primary science: taking the plunge, 2nd edn. Heinemann Educational, Portsmouth

Jirout JJ (2020) Supporting early scientific thinking through curiosity. Front Psychol 11:1717. https://doi.org/10.3389/fpsyg.2020.01717

Keifert D, Stevens R (2019) Inquiry as a members' phenomenon: young children as competent inquirers. J Learn Sci 28(2):240–278. https://doi.org/10.1080/10508406.2018.1528448

Lehn B (1998) What is a scientist. Lerner Publishing Group, Minneapolis

Lynneth S, Curtis KN, Hayes-Messinger A (2017) Children's exploration of physical phenomena during object play. J Res Child Educ 31(1):122–140. https://doi.org/10.1080/02568543.2016.1244583

Mestagh N (2014) Strong walls. In: Inquiry-based activities for primary children: 3–5 years. Malta Council for Science and Technology, Malta, pp 61–64

National Research Council (2000) Inquiry and the national science education standards: a guide for teaching and learning. National Academy Press, Washington, D.C.

Osborne J, Black P, Smith M, Meadows J (1990a) Light: primary SPACE project research report series. Liverpool University Press

Osborne J, Wadsworth P, Black P, Meadows J (1990b) The earth in space: 9 primary SPACE project research report series. Liverpool University Press

Papandreou M, Terzi M (2011) Exploring children's ideas about natural phenomena in kindergarten classes: designing and evaluating 'eliciting activities'. Rev Sci Math ICT Educ 5(2):27–47. https://doi.org/10.26220/rev.887

Papandreou M, Kalaitzidou K (2019) Kindergarten teachers' beliefs and practices towards elicitation in science teaching. Educ J Univ Patras UNESCO Chair 6(1):99–110. https://doi.org/10.26220/une.2956

Rhodes M, Cardarelli M, Leslie SJ (2020) Asking young children to "do science" instead of "be scientists" increases science engagement in a randomized field experiment. Psychol Cognit Sci 117(18):9808–9814. https://doi.org/10.1073/pnas.1919646117

Russell T, McGuigan L (2016) Encouraging the expression of ideas. Exploring science with young children: a developmental perspective, 1st edn. SAGE Publications, London

Terry R, Watt D (1990) Evaporation and condensation: primary SPACE project research report series. Liverpool University Press

Terry R, Longden K, McGuigan L (1990) Rock soil and weather: primary SPACE project research report series. Liverpool University Press

Terry R, McGuigan L, Hughes A (1998) Forces: primary SPACE project research report series. Liverpool University Press

Tullos A, Woolley JD (2009) The development of children's ability to use evidence to infer reality status. Child Dev 80(1):101–114. https://doi.org/10.1111/j.1467-8624.2008.01248.x

UNESCO (1972) Convention concerning the protection of the world cultural and natural heritage. UNESCO, Paris. https://whc.unesco.org/archive/convention-en.pdf. Accessed 8 Aug 2022

Van de Keere K (2014) Let's float! In: Inquiry-based activities for primary children: 3–5 years. Malta Council for Science and Technology, Malta, pp 33–37

Van Meeteren B, Zan B (2010) Revealing the work of young engineers in early childhood education. Early Childhood Research and Practice (SEED—STEM in Early Education and Development) University of Illinois, Urbana-Champaign US

Watt D, Terry R (1990) Sound: primary SPACE project research report series. Liverpool University Press

Zhang M, Xiong K, Wang X, Zhao X (2022) Natural beauty and esthetic value of natural world heritage sites: a literature review and implications for karst geoheritage sites. Geoheritage 14:84. https://doi.org/10.1007/s12371-022-00714-8

An Educational Perspective on the Connections Between Physics and Mathematics

Gesche Pospiech

Abstract Among the methods of physics, the use of mathematics is one of the most important features but is also deemed as one of the most complex and even terrifying aspects of physics learning. To clarify the educational pitfalls and opportunities, this situation requires a deep analysis of the different aspects of mathematization in physics, especially of the role of technical and structural skills. Various possibilities of communicating or representing the connection between physical processes and mathematical structures are important in this respect. An analysis of the students' difficulties and competences hints to promising strategies in teaching the transition between physics and mathematics. In this context, teachers' awareness of the different roles of mathematics in physics and possible difficulties and abilities of students is of central importance. We describe the span of possible student and teacher views and strategies in coping with the connection of mathematics and physics and describe further research needs.

1 Introduction

Physics as a science relies heavily on the use of mathematics. However, the relationship of the two sciences is not as straightforward as it sometimes seems. To shed light on this, we look at the perception of physicists and mathematicians as experts in the interrelated field of mathematics and physics. Some selected quotations out of the many available sources may serve for setting the scene:

> "Mathematics is a part of physics. Physics is an experimental science, a part of natural science. Mathematics is the part of physics where experiments are cheap." V. I. Arnold, Presentation Palais de Découverte in Paris on 7 March 1997

> "Mathematics is a language plus reasoning; it is like a language plus logic. Mathematics is a tool for reasoning." Feynman (1965)

G. Pospiech (✉)
Department of Physics, TU Dresden, 01062 Dresden, Germany
e-mail: gesche.pospiech@tu-dresden.de

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2023
J. Borg Marks and P. Galea (eds.), *Physics Teacher Education*,
Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-44312-1_3

What do these quotations mean and imply about the relation of mathematics and physics? Do they imply: mathematics *and* physics or mathematics *in* physics or physics *in* mathematics? Or do they imply: mathematics and physics, *related* to each other? Or are mathematical elements *inherent* in physics, thus both sciences cannot be separated? What are the basic broad outlines for the role of mathematics in the context of physics? In which way can these be important for teaching and learning?

1.1 Historical Aspects

As early as the beginning of physics in antiquity, several aspects of mathematical elements were evident:

> Geometry: The regular platonic bodies as geometrical elements served as a model for the structure of matter.
>
> Algebra: The Pythagoreans found the relation of small numbers representing the harmonies in music. In mathematics, this led to unwished for complications, as SQRT(2) is not a rational number, but in physics, it implied that the description of processes by numbers is possible.
>
> Laws: In astronomy, the motion of planets was represented by numbers and geometry relating space and time. It took a long time to recognize the laws behind these numbers.

Besides these early mathematical descriptions, there were the purely qualitative descriptions in Aristotelian physics not needing mathematics. Also later, e.g. at the beginning of studies on electrostatics, no mathematics was required. Only even later on, in the progress of science, the evaluation of experimental data increasingly required mathematical techniques. The more precise the instruments became, the more important it became to structure the data and it was possible to develop corresponding laws (Boniolo and Budinich 2005). As a consequence, it became necessary to have more precise laws that could cope with the precision of experimental data by allowing for precise and testable predictions. Examples besides astronomy are: the laws of the ideal gas, Ohm's law, and others. From this viewpoint, the use of mathematics in physics was also driven by experiments, by increasingly exact instruments and by precise data.

Another big step was the development of physics in the seventeenth century, leading to understanding and explaining the motion of bodies. Shortly before Newton, Huygens used the method of infinitesimal geometrical analysis, which was later on replaced by the modern calculus with much more flexible applicability. In addition, Huygens used algebraic expressions in a new way to discover new insights and predict results, for example, the behaviour in collisions (Hyslop 2014; Kanderakis 2016). For this, he applied three methods of representation—the diagram, the language of geometry and algebraic formulations. The interplay of these representations was used as scaffolding and from this "conceptual analysis, a new principle—quantity of motion with direction—was produced" (Hyslop 2014). Conversely, the algebraic calculation pushed forward the understanding of collisions and hence of corresponding basic physical concepts. Far beyond went the development of calculus by Newton and Leibniz which opened a whole new area of research in physics, more exactly in mathematical physics, and allowed building fundamental theories.

Here, my focus lies on the acceptance of this development by the learners, the (amateur) physicists of that time, because this might be enlightening for educational purposes. Gingras (2001) dates the start of the increasingly intense mathematization to the times of Newton. He contrasts the Newtonian approach with the Descartes method of qualitatively but rigorously discussing physics phenomena. He also analyses the influences of the increasing use of mathematics on the physics method and spoke of “unintended consequences”. One of the consequences coincides very much with the impression and thoughts many people have today: actors (learners) are excluded if they do not understand and master the necessary mathematical tools, methods and ways of thinking. As Faraday wrote to Maxwell: “I was at first almost frightened when I saw such mathematical force made to bear upon the subject and then wondered to see that the subject stood it so well” (Gingras 2001). To draw the line to education: The German physics educator Martin Wagenschein (1896–1988) spoke about the “initiated”, people knowing physics and mathematics who can cope with it quite easily, and the “intimidated”, the school students that ought to learn physics and have their difficulties with the mathematical description. Moreover, it is also frequently observed that if somebody does not use the mathematical description, he or she is thought to do no longer “real” physics, but as a teacher told me, they are doing (only) “housewife physics”. On the other hand, when mathematics is used intensively, there is a possibility that the art of physical reasoning without formulas or geometric theorems will be lost. Here, we are on a tightrope walk, between different perspectives: mathematical elements and structures play an increasingly important role in physics, more so in recent times. For example, the Maxwell equations led to new phenomena such as the existence of electromagnetic waves and implied special relativity theory. However, numerous physical concepts can also be explained without mathematics. Taken together we can say that mathematics is inherent in physics as it is done today. So, teaching physics implies teaching physics concepts and the inherent mathematics with it. In the following, we will analyse some aspects of this situation.

1.2 Aspects from Physics as a Science

Here, we describe briefly central aspects of the role of mathematics in doing physics.

Explanation If we assume that the goal of physics is to explain natural processes, the question arises as to what is meant by an explanation. Here, we focus on the role of mathematics in this process. We can assume that before Newton a physical process was explained using qualitative physical concepts (Gingras 2001). After Newton, the predictive power of mathematical formulation became so strong that sometimes mathematical calculation was trusted more than physical intuition and hence served as a kind of explanation. As mentioned above, the self-awareness of physicists and their image of physics as science plays a role: Are qualitative-physical explanations regarded as equivalent to mathematically based explanations? Is there always a complete purely qualitative-physical explanation at all?

Idealization Another aspect is nowadays so self-evident for physicists and physics teachers that it is sometimes (too much) taken for obvious and no longer explicitly mentioned or taught in class: the idealization, i.e. the neglect of physical parameters under certain circumstances. In this case, it is pretended that some effects, e.g. friction, do not exist or can be neglected as e.g. friction in free fall, while they are important or even necessary for (other) real processes, such as, e.g. friction in the process of walking.

Structural role of mathematics in physics We have a formalization in physics on different levels and with different tools. For deeper analysis, it might be helpful to distinguish a technical and a structural role of mathematics in the doing of physics (Pietrocola 2008). On the structural side, it becomes visible that both sciences are interwoven in a way that "these two distinct areas of knowledge have mutually supported each other" in their progress (Galili 2018).

1.3 Educational Aspects

What does this discussion on the role of mathematics in physics imply for teaching the nature of physics? With respect to school education, on the basis of scientific theory, four specific roles were identified that mathematics fulfils in physics (Krey and Mikelskis 2010): communication, precision, objectivity and reduction of cognitive load. An important aspect is the facilitation of communication by concise formula notation. The associated brevity, on the other hand, can also pose a difficulty for learners as the formula signs all carry an additional conceptual meaning leading to fundamental difficulties (see 2.2.; (Kanderakis 2016)). The complexity of the process of unpacking the dense information in formulas was described by Redish and comprehensively analysed by Kuske-Janßen (2020), s.a. (Pospiech and Fischer 2021; Redish and Kuo 2015). In addition, even if the mathematical notation is known, the handling of mathematical terms in physics requires additional experience and familiarity with its use. So, the reduction of cognitive load can only be reached after a process of habituation. Another path to give insight into the interplay is given by modelling (Pospiech and Fischer 2021). Modelling combines mathematics and physics in several aspects:

- on the physics side: idealization, adapted to the situation (friction, centre of mass)
- on the technical side of mathematics: approximation
- on the structural side of mathematics: mathematical structures are mapped to physics.

2 Teaching and Learning the Interplay of Physics and Mathematics

Teaching physics at school also implies teaching the methods of physics and the nature of physics including the use of mathematical means. Even if the full depth and ramifications of the interplay between physics and mathematics cannot be taught in school, based on the analysis just given, we will argue which aspects are sufficiently important, can be prepared for school teaching and (might) lead students to a deeper understanding of the physical method.

2.1 The School Physics Perspective on Mathematics

The central concern of teaching physics is that the students should learn the physics concepts as a first priority. Often mathematics, in the sense of algebra, i.e. formulas and their manipulation, is considered much less important. However, several aspects have to be considered:

- Idealizations we are using to describe physics processes have a computational counterpart, namely approximations, which on their part rely on quantitative estimations of the relevance of one or other parameter, be it friction, resistance of wires in electric circuits, approximation of parallel rays in diffraction pattern, etc., implying that any idealization has to be justified in numerical, mathematical terms.
- Performing and evaluating experiments, relies on mathematics in a quite broad sense: numbers have to be taken, to be presented in tables and/or graphs and the type of an underlying function is conjectured. The physics content lies partly in the units of the physics quantities and partly in the identification of an appropriate function, perhaps linear or quadratic or exponential, describing the dependency of the quantities involved in accordance with physics theory, for example, obeying conservation laws. The precise dependency often can be justified by invoking mathematical tools such as integration or differentiation.
- The results of physics processes can, in some cases, be predicted qualitatively. For example, the behaviour of a gas in thermodynamics: if an enclosed gas is heated then its pressure rises. But in order to give a precise prediction the underlying law has to be known, be it represented graphically or algebraically, and the values then can be read off or calculated.

From these aspects the question arises if physics can be done at all without any mathematics: would this be possible only on the basis of concepts and (non-mathematical) models? I would answer with a cautious “partly”: The answer also depends on what kind of reasoning is considered to be with or without mathematics. This decision is by no means unique. Without mathematics, it might be considered that the concept of heat can be explained by the particle model, interacting only by collisions, up to a certain degree, or that experiments from electrostatics help to decide if materials can be "electrified". On the other hand: Do the magnetic field lines invented and made visible by Faraday, belong to mathematics or to physics? Here, we move to the border of a qualitative and a quantitative description, where we cannot decide if it is "pure physics" or "physics mixed with mathematical tools". Additionally, the existence of this border depends on several decisions:

- If physics can be taught only with mathematics there is no border at all; only the intensity of the use of mathematics is varying. Strictly speaking, numbers belong to mathematics; as soon as we use some numbers and compare them we no longer have "pure physics".
- If mathematics only means algebra, formula, functions and so on, then the whole formalization of physics processes by geometrical means would not count among the use of mathematics, as, for example, Faraday's field lines.

Galili (2018) argues with historical examples for a mutual support of mathematics and physics and also that algebraic and geometrical representations of physics processes enrich each other and provide a more complete picture than one representation alone (Greca and Moreira 2002). In this sense, geometry belongs to the mathematical description. Hence, physics concepts might be represented by physical–mathematical models or mathematical models, which are then formalized by geometry, graphs or algebra.

After discussing the interrelation of physics and mathematics and accepting that we cannot always separate them beyond doubt but should happily use them intertwined, we undertake the task of studying this interplay in more detail.

2.2 Aspects of the Interplay: Syntax, Semantics and Communication

One viewpoint concerns the distinction of technical and structural skills corresponding to the syntactic and semantic level of the interplay (Pietrocola 2008; Greca and Moreira 2002). Syntax concerns the rules for building mathematical expressions. But in physics and mathematics, there exist different conventions, with unforeseen difficulties encountered by the students. Semantics concerns the giving and extracting meaning of mathematical expressions in physics and is highly relevant for analysing problems we treat with equations in physics. In Kuske-Janßen (2020) (see also Pospiech and Fischer 2021), a model for the verbalization of formulas and their sense-making is described that relates syntax and semantics in a systematic way. It identifies different levels of abstractness of verbalization and explicitly considers the conceptual meaning of physical formulas in the framework of a theory as well as their everyday relevance. Therefore, this model seems to be appropriate for use in school, for shaping and analysing teaching and learning processes and for diagnosing the strategies and difficulties of students in coping with the interplay of physics and mathematics or with the transfer between the two school subjects.

Both these aspects can be enriched by the aspect of communication (Ataide and Greca 2013), which was also highlighted in Krey and Mikelskis (2010) as one of the important functions of mathematics in physics, because in teaching and learning the teachers and students have to present their thinking and their results to support physics learning. In the following, we consider possible skills, attitudes and strategies including the communicative aspects, (Ataide and Greca 2013) (see Fig. 1).

The differentiation between these three aspects (syntax, semantics and communication) clarifies the origin of possible learning difficulties and allows for a more differentiated view beyond "students do not know math". In this context, it might be interesting to know that even in mathematics educators and teachers face similar problems: an instrumentalized learning versus a relational learning (Skemp 1976) and the possibility of using inadequate "Grundvorstellungen" (basic concepts) (vom Hofe and Blum 2016). Therefore, we are led (and supported by some evidence (Aufschnaiter et al. 2000)) to assume that the main difficulty of students lies in the transfer of knowledge from mathematics to the domain of physics, the switching between the

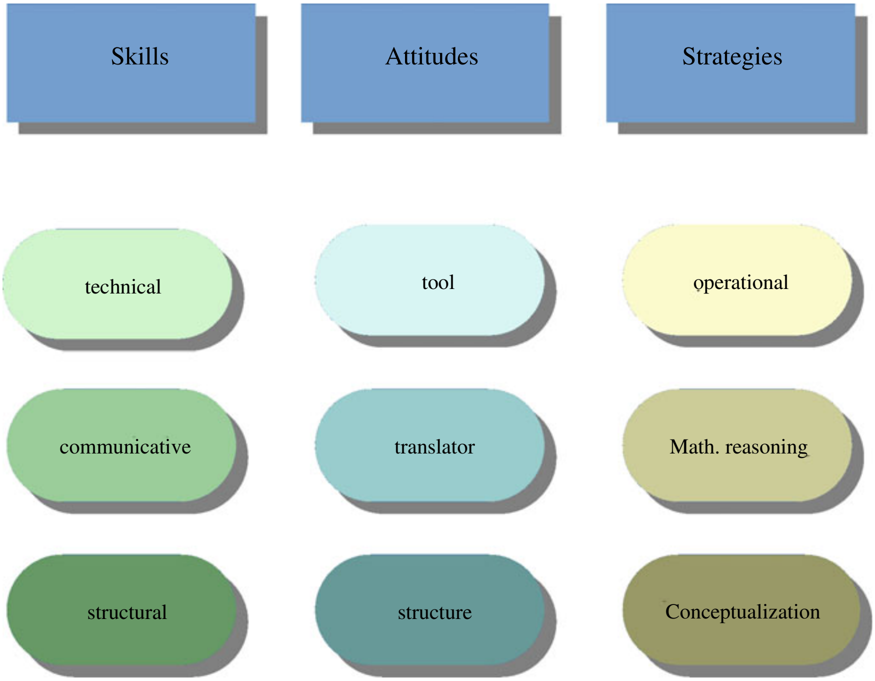


Fig. 1 The categories of skills, possible students' attitudes and their problem-solving strategies (columns) are graphically visualized. In the rows, the corresponding characterizations are given. This should be read as follows: the technical skill is used by students who often have an attitude towards mathematics as a tool and apply in their problem-solving often operational strategies (see Ataide and Greca 2013)

areas of knowledge and thinking: mathematics and physics both require the identification of structures but nevertheless have different topics, objects, perspectives and methods, which we illustrate by an example:

Example: algebraic expressions Handling algebraic expressions (formulas) is central for doing physics. While in mathematics, numbers or symbols in algebraic terms or functions usually have no further meaning, in physics, these symbols are almost always connected with physics units, but in any case with a physical meaning. This meaning does not stop at the assignment of the symbol, for example "F means force", but in addition, as a rule, deeper physical concepts are hidden behind this relation of name and symbol, receiving its full meaning only in the context of a theory (Kanderakis 2016; Pospiech 2019).

Status of equations, variables, parameters While already in mathematics itself the handling of equations with their variables and parameters is very complex for most students and often not quite mastered, this situation is aggravated in physics as described in the previous example. The reason lies in the fact that different quantities can be either a parameter or a variable depending upon context as was discussed at the example of the ideal gas equation (Kanderakis 2016), that independent and dependent variables are not uniquely determined and that different conventions are used for signs in the equations.

2.3 The Mathematics Perspective

Mathematics has contributions to physics far beyond "formula" and "equation":

- mathematical elements on school level are provided by geometry, algebra and calculus
- advanced areas, usually used at university, are number theory, variational theory, topology, computational techniques, theory of functions or functional analysis
- more or less implicitly mathematical methods are used: logic derivations or methods of proofs.

Another point of view concerns the sequence of teaching physical and mathematical knowledge modules at school. Normally, it is assumed that it is favourable to first learn the mathematical basics before using them in physics. However, there are sometimes proposals, partly born out of necessity, to reverse the sequence. This seems to be possible and might even enhance mathematics learning because physics can provide concrete examples for mathematical constructs that might facilitate learning.

3 Empirical Results

Surprisingly, amazingly little is known about students' views on mathematical elements in physics. Research in physics education has focused on how students understand concepts and has tended to view mathematics in physics lessons in terms of dealing with formulas and as such preventing deep understanding. Therefore, there is still a great need for research on understanding in detail how students deal with mathematical elements and how this is related to understanding physics concepts. However, some informative results have already been achieved in the last 15–20 years which I will present with a focus on physics education in schools and for school students.

3.1 Knowledge and Views of Students

It is well known that students at school and also at university have problems to mathematize physical processes. The quick diagnosis is often made that it is due to a lack of knowledge in mathematics and its application—a well-known teachers' myth. However, this assumption falls short.

Mathematical requirements in exams This last claim is supported by various findings. In Germany, tasks in the written final examination of the Gymnasium (taken in the age of 18–19 years and allowing entrance to university) were analysed for their mathematical requirements. It became clear that the majority of these tasks needed only the material of the intermediate school level and not the mathematics of the upper level of the Gymnasium (corresponding to high school). In addition, the focus was on technical skills rather than structural reasoning (Schoppmeier et al. 2012). So, where does the problem lie? Observation of students' problem-solving showed that they tend to work in either a mathematical mode or in a physical mode (Aufschnaiter et al. 2000), and find it hard, for example, to allocate mathematical symbols a physical interpretation. Therefore, the lack of mathematical procedural skills in the narrower sense—we also call them technical skills—is probably not primarily the cause of the observed problems. This has been shown with the example of graphs (Planinic et al. 2013; Ivanjek et al. 2016).

Graphs in physics learning There has been extensive research on students' use of linear functions and their graphical representation (McDermott et al. 1987; Leinhardt et al. 1990; Beichner 1994; Hale 2000; Friel et al. 2001; Aberg-Bengtsson and Ottosson 2006; Wemyss and van Kampen 2013). Typical errors in the interpretation of graphs in a physical context have been known for a long time, such as height—slope confusion or image interpretation (Planinic et al. 2013; Ivanjek et al. 2016). These findings mostly relate to kinematics, where there are also extensive conceptual problems that overlap with the problems of interpreting graphs. This led to research on the relation of mathematical knowledge and physics knowledge (Planinic et al. 2013; Ivanjek et al. 2016; Woolnough 2000; Christensen and Thompson 2012; Planinic et al. 2012). Students may effortlessly identify the “intercept” and “slope” in linear equations working in a mathematical mode ($f(x) = ax + b$), but find it problematic when occurring in a physics formula ($s = s_0 + v_0 t$). This became particularly clear in a study in which students in their first semester at university were given parallel tasks on linear functions from mathematics, physics and another context. The tasks from physics were solved significantly worse than the purely mathematical tasks and even the tasks from other contexts. It was also noticeable that in non-physical contexts more variable solution strategies were used (Ivanjek et al. 2016).

On the other hand, there is considerably less literature on constructing graphs. Some studies of how children intuitively construct graphs show features that still appear later in high school and college students such as pointwise connection, typical mistakes in labelling axes and so on. There are also studies on the reasoning in making graphs (Wavering 1989; McKenzie and Padilla 1986; Hammer et al. 1991; Mevarech and Kramarsky 1997; Roth and McGinn 1997; Erickson 2006). But in this area, much research with the perspective of diagnosing students’ knowledge and recommending teaching strategies remains to be done.

Algebraic expressions in physics learning Algebraic expressions, formulas or equations are at the centre of physics education. They have, as described above, a central role, which is also expressed in the perception of the students (Krey and Mikelskis 2010). Considering this importance, for a long time there was surprisingly little research on the understanding of formulas and how students deal with them. This has changed only in recent years. In light of what was said earlier, the issue is to keep a balance of syntax, semantics and the communicative role of formulas in teaching. Ground-breaking was the work of Sherin (2001) on possible student conceptions with equations highlighting the role of “symbolic forms”. Additional results on how younger students aged 15–16 interpreted algebraic expressions and functions found that often mathematical and physical interpretations interfere with each other and that the importance of using and knowing syntax (including differences between physics and mathematics) in the understanding process should not be underestimated (Uhden 2016).

3.2 Students’ Strategies in Problem-Solving with Focus on the Interplay of Physics and Mathematics

Problem-solving is an important, if not the central part, in studying physics. However, it has been shown time and again that learners have great difficulty in finding a solution with favourable solution paths to given problems. Therefore, there is naturally a great emphasis on research on this topic. It is in the nature of the problems treated in physics that they often involve a combination of mathematical and physical skills. However, the model by Pospiech (2019) clarifies that the boundary between the knowledge domains is not sharp, but there is a large overlapping part—the physical–mathematical modelling. This process requires creativity, intuition and experience. Hence, one has to take into account that learners are novices who, due to their limited experience, cannot proceed as efficiently as experts. This raises the question of how to help learners pursue appropriate strategies. This shows similar difficulty as trying to overcome everyday beliefs about physical concepts. Here, it might help to investigate which strategies learners use on their own to solve given problems. An important step in this direction was the identification of "epistemic games" among college students—some seem more adequate than others (Tuminaro and Redish 2007; Redish et al. 2006). Likewise, strategies and difficulties of students aged 15–16 could be identified which additionally suggests interference of mathematical and physical–conceptual difficulties (Uhden 2016). This study also revealed that students sometimes take perplexingly good paths. Also, in other data, quite expert-like strategies in learners were observed (Eichenlaub and Redish 2019). But the learners needed significantly more time to complete the tasks than experts. In both studies with individual cases, the phenomenon emerged that the learners trusted mathematics rather than their physical intuition. This is in line with Ivanjek et al. (2016) (see also (Kanderakis 2016)). High-quality strategies during transfer between different mathematical representations (graph, formula, table) were also observed in students of grade 8 (14–15 years) (Geyer and Pospiech 2019; Geyer and Kuske-Janßen 2019). Students would use strategies with a focus on mathematics or with a focus on physics but some would also apply balanced strategies.

3.3 What Are Teachers Saying and Doing?

Teachers have a great impact on their students' attitudes and learning. Therefore, it is also very important to know what teaching strategies they use in the field of mathematization and what effect these measures have. Unfortunately, very little is known about the actual practices and their effect in particular. There are first results on the connection of language and formulas (Kuske-Janßen 2020) and the global approaches, so-called teaching patterns (Turşucu et al. 2017; Lehavi 2017, 2019). The use of physical–mathematical modelling in the classroom was analysed in Angell et al. (2004), Freitas et al. (2004), Hansson et al. (2015), see also Pospiech and Fischer (2021) and the stance of prospective teachers on the role of mathematics in physics in Ataide and Greca (2013), Carrejo and Marshall (2007). This stance is important because it influences the way of teaching. It seems throughout that many teachers focus on technical skills and on treating application problems quantitatively, but the structural role of mathematics is often not explicitly and deliberately addressed.

Language in teaching formulas In Kuske-Janßen (2020), a "level model" of the verbalization of formulas was developed, defined in Kuske-Janßen (2020) and briefly explained in Pospiech and Fischer (2021) (also Sect. 2.2). This model works as follows:

The formula is stated in a direct mathematical way, decribed by levels 1–3.

The formula is applied or interpreted: This corresponds to levels 4–6, referring to different language levels (everyday, erudite, special language).

The formula is discussed: This is a meta-level. These statements do not concern the content of the formula, but they represent epistemological views and convictions, describe explicitly or implicitly the kind of statements a formula makes, and reflect the role of formulas within physics and physics education.

This model was used to analyse lessons in grade 8 of lower secondary school in Saxony, Germany. The topic was the laws of electrical resistance: definition of resistance, Ohm's law and resistance of a long thin wire (Kuske-Janßen 2020). In this study, the levels of verbalization used by teachers were identified and the described model was confirmed. Levels 4–6 present by far the majority of the utterances during lessons. A clear emphasis is to be seen with the categories' relationship between variables, individual variables and calculation. This indicates that the focus is on technical handling with a low proportion of explanations. The meta-level, reflection on and evaluation of formulas, is usually used implicitly. A detailed analysis of the distribution of codings among the teachers shows that they have very different emphases or preferences in their teaching. But on the whole, most teachers use a broad spectrum of ways to introduce and use or explain formulas.

Teachers' epistemic views of the interplay with respect to their teaching In an interview study, the views of experienced physics teachers were explicitly elicited. They should describe which strategies they use in teaching and why, and what their experiences were (Lehavi et al. 2019; Pospiech et al. 2015). Besides overarching teaching patterns, basic favourite teaching principles could be identified (Pospiech et al. 2015):

- concept-related: This teaching principle is characterized by statements such as: "I like it more first to induce an understanding before I treat it with math." Two teachers mention this viewpoint more often and regard it is important to first treat the concepts before they go to the mathematical description. The focus lies on the physics side with some structural elements of the interplay.
- math-related: This teaching principle is characterized by statements such as: "I always try to explain it again and again starting from math. So that they understand it there also." Also two teachers make strong use of mathematics. These teachers tend to stress the technical role but this does not imply that they neglect the structural or language aspect.
- application-related: This is the biggest group of teachers. 6 out of 13 emphasize especially the importance of relating physics to applications or visualization, e.g. by statements like: "It is important that the practical aspect of physics does not fall short." Often the motivation of students and shaping the learning process from the concrete is the reason for this aspect.
- multifaceted: Three teachers show no specific focus in their goals but seem to cover several aspects equally.

Patterns A different focus was chosen in Lehavi et al. (2017, 2019). From interviews with experienced teachers about their approach to teaching, and from classroom observations, four teaching patterns could be identified that might promote structural skills in different ways. These patterns describe, for example, how teachers derive laws from data or first principles (construction pattern) or what are the implications of a law in special cases (exploration pattern) or to recognize analogies with help of mathematics (broadening pattern). In addition, an application pattern concerning problem-solving was found (Lehavi et al. 2017).

4 Conclusion and Implications

Put together, the theoretical analysis shows that structural elements are so inherent in the interplay of mathematics and physics that often the differences in syntax and the importance of additional semantics in physics are overlooked. Therefore, the possible difficulties of learners often are underestimated and consequently suitable ways for reducing them by appropriate measures are missed. On the other hand, empirical research gives evidence that even students at a relatively young age may already have adequate understanding and are able to apply advanced strategies.

4.1 What Can Be Recommended to Teachers?

In teaching, attention should not be paid to the learners' shortcomings, but to their abilities. Teachers should be aware that their students may take a long time for merging mathematics and physics and may not always get the right result, even if they use appropriate or expert-like strategies. Therefore, it is important to give students time for their solution paths and to encourage reflection at selected points. If the students then better relate mathematical results and their own physical intuition, this will support their satisfaction and a positive attitude (Kuo et al. 2015). Different paths can be taken to achieve this:

> One may discuss in detail the meaning of formulas, not only in their formal aspects but especially in their meaning for concrete situations (Kuske-Janßen 2020; Eichenlaub and Redish 2019).
>
> Students may be given the task of developing and interpreting their own formulas in a stimulating context that is close to them. There may be no right or wrong, but only more or less convincing argumentations (Redish et al. 2006; Eichenlaub and Redish 2019),
>
> Teachers may point out proper approaches, encouraging students to take flexible solution paths.

In Turşucu et al. (2020), it is recommended that mathematics and physics teachers work well together and explicitly ensure in their lessons that students in physics classes recognize the algebraic techniques from mathematics classes and make sense of them accordingly. This means, of course, that both subjects are taught in a concept- and understanding-oriented way, without neglecting the manual technical skills.

4.2 *What is Still to Be Researched?*

The next research step would be to develop numerous teaching units—with or without using digital media—in which students learn how to deal with mathematization at different levels and with different emphases, and to study the effectiveness and impact of these units. One branch of this research would be a systematic approach to the use and interpretation of formulas including different forms of representation as, for example, also the linguistic handling of formulas. Another research branch would be the creation of graphs (Wavering 1989; Erickson 2006) from experiments, i.e. a systematic teaching and learning of the evaluation of experiments.

References

Aberg-Bengtsson L, Ottosson T (2006) JRST 43:43
Angell C, Guttersrud O, Henriksen EK, Isnes A (2004) Sci Educ 88:683
Ataide ARPd, Greca IM (2013) Sci Educ 22:1405
Aufschnaiter S, Aufschnaiter C, Schoster A (2000) ZfDN 6:37
Beichner RJ (1994) Am J Phys 62(8):750–762
Boniolo G, Budinich P (2005) The role of mathematics in physical sciences. Boniolo G, Budinich P (eds). Springer, Dordrecht, pp 75–96
Carrejo DJ, Marshall J (2007) Math Educ Res J 19:45
Christensen WM, Thompson JR (2012) Phys Rev Phys Educ Res 8 023101
Eichenlaub M, Redish EF (2019) Blending physical knowledge with mathematical form in physics problem solving. In: Pospiech G, Michelini M, Eylon BS (eds) Mathematics in physics education. Springer, Cham, pp 127–151
Erickson T (2006) Teach Math Appl 25:23
Freitas IM, Jiménez R, Mellado V (2004) Res Sci Educ 34:113
Friel SN, Curcio FR, Bright GW (2001) J Res Math Educ 32:124
Galili I (2018) Sci Educ 27:7
Geyer MA, Kuske-Janßen W (2019) Mathematical representations in physics lessons. In: Pospiech G, Michelini M, Eylon BS (eds) Mathematics in physics education. Springer, Cham, pp 75–102
Geyer MA, Pospiech G (2019) An explorative laboratory study: changing representations of functional dependencies in physics class of lower secondary school. In: McLoughlin E, Finlayson OE, Erduran S, Childs PE (eds) Bridging research and practice in science education. Springer, Cham, pp 35–50
Gingras Y (2001) Hist Sci 39:383
Greca IM, Moreira MA (2002) Sci Educ 86:106
Hale P (2000) Math Teach 93:414
Hammer D, Sherin B, Kolpakowski T and others (1991) J Math Behav 10 117
Hansson L, Hansson O, Juter K, Redfors A (2015) Sci Educ 24:615
Hyslop SJ (2014) Found Sci 19:35
Ivanjek L, Susac A, Planinic M, Andrasevic A, Milin-Sipus Z (2016) Phys Rev Phys Educ Res 12:010106

Kanderakis N (2016) Sci Educ 25:837

Krey O, Mikelskis HF (2010) The role of mathematics—the students point of view. In: Tasar M, Cakmakci GM (eds) Learning and assessment. Academia, Istanbul, pp 67–72

Kuo E, Hallinen NR, Conlin LD (2015) How prompting force diagrams discourages student use of adaptive problem-solving shortcuts. In: Chrukian A, Dyan LJ, Ding L (eds) 2015 physics education research conference (College Park, MD: Compadre), pp 183–186

Kuske-Janßen W (2020) Sprachlicher Umgang mit Formeln. Logos, Berlin

Lehavi Y, Bagno E, Eylon BS, Mualem R, Pospiech G and others (2017) Classroom evidence of teachers' pck of the interplay of physics and mathematics. In: Greczyło T, Dębowska E (eds) Key competences in physics teaching and learning. Springer, Cham, pp 95–104

Lehavi Y, Mualem R, Bagno E, Eylon BS, Pospiech G (2019) Taking the phys-math interplay from research into practice. In: Pospiech G, Michelini M, Eylon BS (eds) Mathematics in physics education. Springer, Cham, pp 335–353

Leinhardt G, Zaslavsky O, Stein MK (1990) Rev Educ Res 60:1

Linder C (2013) Eur J Sci Math Educ 1:43

McDermott LC, Rosenquist ML, Van Zee EH (1987) AJP 55:503

McKenzie DL, Padilla MJ (1986) J Res Sci Teach 23:571

Mevarech ZR, Kramarsky B (1997) Educ Stud Math 32:229

Pietrocola M (2008) Mathematics as structural language of physical thought. In: Vicentini M, Sassi E (eds) Connecting research in physics education with teacher education. ICPE, New Delhi

Planinic M, Milin-Sipus Z, Katic H, Susac A, Ivanjek L (2012) IJSME 10:1393

Planinic M, Ivanjek L, Susac A, Milin-Sipus Z (2013) Phys Rev Phys Educ Res 9:020103

Pospiech G (2019) Framework of mathematization in physics from a teaching perspective. In: Pospiech G, Michelini M, Eylon B (eds) Mathematics in physics education. Springer, Cham, pp 1–33

Pospiech G, Fischer HE (2021) Physical–mathematical modelling and its role in learning physics. In: Fischer HE, Girwidz R (eds) Physics education. Springer, Cham, pp 201–229

Pospiech G, Eylon BS, Bagno E, Lehavi Y, Geyer MA (2015) Il Nuovo Cimento 38:110

Redish EF, Kuo E (2015) Sci Educ 24:561

Redish EF, Scherr RE, Tuminaro J (2006) Phys Teach 44:293

Roth WM, McGinn MK (1997) Sci Educ 81:91

Schoppmeier F, Borowski A, Fischer HE (2012) PhyDid A 11:28

Sherin BL (2001) Cogn Instr 19:479

Skemp RR (1976) Math Teach 77:20

Tuminaro J, Redish EF (2007) Phys Rev Phys Educ Res 3:020101

Turşucu S, Spandaw J, Flipse S, de Vries MJ (2017) IJSE 39:587

Turşucu S, Spandaw J, de Vries MJ (2020) Res Sci Educ 50:2131

Uhden O (2016) ZfDN 22:13

vom Hofe R, Blum W (2016) J Math-Didakt 37:225

Wavering MJ (1989) J Res Sci Teach 26:373

Wemyss T, van Kampen P (2013) Phys Rev Phys Educ Res 9:010107

Woolnough J (2000) Res Sci Educ 30:259

Recent Developments in Physics Teacher Education in the USA: Toward a Broad Research Agenda

Stamatis Vokos

Abstract A 4-year investigation on the status of Physics Teacher Education (PTE) in the USA led to the publication of an extensive report (https://www.phystec.org/webdocs/TaskForce.cfm) that called the nation to action to increase the number and improve the preparation of teachers of physics. In recent years, the PhysTEC project has engendered a powerful community of physics teacher educators, researchers, policymakers, and leaders of professional societies, who are committed to the improvement and sustainability of PTE programs. As a result of this strategic work, research and practitioner books have been published, marketing projects have been launched, research projects have sprung up. What is now needed is a common research agenda that is informed by research results on the preparation and support of novice and veteran science teachers yet take into account the particularities and the special habits of mind, habits of practice, and habits of maintenance associated with the physics enterprise. In this paper, a theoretical framework is presented, and several possible research questions are outlined. It is hoped that this paper will serve as a starting point for conversation with colleagues involved in PTE within and outside the United States to enrich the proposed research agenda with the unique strengths of their perspectives.

1 Introduction

In many ways, physics teacher education (PTE) in the USA has currently features that are similar to those it has had for the last 130 years. For instance, the production of more than five physics teachers per year is concentrated in a handful of institutions and the most frequent number of physics teachers prepared per year at an institution is zero. Yet, other features are profoundly different. There is a powerful national network of institutions that are committed to physics teacher education. The PhysTEC project, spearheaded by the American Physical Society, with the

---

S. Vokos (✉)
Physics Department, California Polytechnic State University, San Luis Obispo, CA 93407, USA
e-mail: svokos@calpoly.edu

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2023

J. Borg Marks and P. Galea (eds.), *Physics Teacher Education*,
Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-44312-1_4

American Association of Physics Teachers, has provided national leadership and funding, drastically increasing the number of institutions engaged in PTE, elevating the visibility of PTE, supporting PTE institutional champions, organizing international meetings on PTE, publishing scholarly books, as well as books for practitioners, and promoting programmatic improvements based on carefully developed self-assessment rubrics. In this sense, PhysTEC has promoted national experiments on PTE, and the thoughtful dissemination of their results, at a scale that the USA has never seen before. It is fair to say that we understand the challenges as a nation better than ever before, we have a blueprint for action that is not one-size-fits-all by recognizing and leveraging distinctives of different institutional missions, and we have scores of institutions that have developed capacity to engage in PTE in sustainable ways, without depending exclusively on continuing funding from external grants.

Physics education research (PER) emerged in the last 45 years and initially focused, almost exclusively, on cognitive aspects of learning physics topics. As the field is maturing, it has been expanding its reach to additional aspects of the physics learning enterprise. This work, together with broader research on teacher education and teacher learning, has led us to *articulate* features of effective PTE programs. A few years ago, a theoretical framework was proposed that *explains* these features. Yet, there is so much that we still do not know. Later in this paper, we suggest research questions for the consideration of the field. But first, we summarize what is already known.

We draw heavily upon the findings of the 4-year investigation of the National Task Force on Teacher Education in Physics (T-TEP) (Meltzer et al. 2012), which was instituted by the American Physical Society, the American Association of Physics Teachers, and the American Institute of Physics. The goal of T-TEP was to survey the landscape of PTE in the USA and make recommendations "for the development of exemplary physics teacher education programs."

2 T-TEP Report: Results

T-TEP produced eight findings (Meltzer et al. 2012).

1. (a) Few physics departments and schools of education are engaged in the professional preparation of physics teachers.

   (b) Physics teacher education programs produce very few graduates, making it difficult to justify dedicated staff, specialized courses, and other resources.
2. Without exception, all of the most active physics teacher education programs have a champion who is personally committed to physics teacher education. With few notable exceptions, these program leaders have little institutional support.
3. Institutional context appears to be a significant factor in the engagement of physics departments in physics teacher education.
4. Few institutions demonstrate strong collaboration between physics departments and schools of education.

5. Physics teacher education programs do little to develop physics-specific pedagogical expertise of teachers.
6. Few programs provide support, resources, intellectual community, or professional development for new physics teachers.
7. Few institutions offer a coherent program of professional development for in-service teachers, even though most current physics teachers are not adequately prepared to teach physics.
8. Thriving physics teacher education programs exist that can serve as models and resources for other institutions.

Such thriving programs are characterized by several of the following features, though no institution had all:

- recognition and support for the champion;
- targeted recruitment of pre-service physics teachers;
- active collaboration between physics departments and schools of education;
- a sequence of courses focused on the learning and teaching of physics;
- early teaching experiences led by the physics department;
- individualized advising of teacher candidates by knowledgeable faculty;
- mentoring by expert physics teachers;
- a rich intellectual community for graduates.

This severe shortage of physics teachers prepared by institutions of higher education with the involvement of physics departments has become even more pronounced since the publication of the T-TEP Report. Magee et al. (Magee et al. 2022) illustrate that the number of physics teachers prepared nationally has dropped by about 25% since 2013, which, however, is also true for all STEM teachers for the same period. In contrast, the number of students taking high school physics has increased by 13% over the same duration.

In recent years, a major recruitment effort in the USA has been launched. (May 2021) As is stated on its website, “Get the Facts Out (GFO) is a five-year, NSF-funded partnership of the Colorado School of Mines and four national societies: the American Physical Society, the American Chemical Society, the American Association of Physics Teachers, and the Association of Mathematics Teacher Educators. GFO is a unique project that is designed to reach STEM majors in a large fraction of all U.S. mathematics, chemistry, and physics departments and has the potential to significantly address teacher shortages in these high-need STEM disciplines.” (GFO website 2022). The project has produced data-informed recruitment tools, including presentations that seek to address common misconceptions about STEM teaching.

Although more research on efficacy of recruitment strategies is definitely needed, I concentrate on questions surrounding the features of thriving physics teacher education programs, identified in the eighth finding above. In particular, is there a theoretical reason for anticipating the features found? Are there new features, as yet not identified, that a theoretical framework would enable us to expect? In 2017, Etkina et al. (Etkina et al. 2017) proposed such a framework, which was termed Development of Habits through Apprenticeship in a Community, DHAC for short.

3 DHAC

The premise of DHAC (Etkina et al. 2017) is that teachers tend to develop "habits with practical experience and under the influence of knowledge and belief structures that in many ways condition the responses of teachers in their practical work. To steer new teachers away from developing unproductive habits directed towards 'survival' instead of student learning, [the authors] propose that teacher preparation programs (e.g., in physics) strive to develop in preservice teachers strong habits of mind and practice that will serve as an underlying support structure for beginning teachers." Therefore, according to the DHAC framework, programs that are not structured in ways that foster the development of helpful habits are unlikely to produce teachers who can navigate the manifold demands of a classroom with deep student learning as the desired outcome.

DHAC is helpful in enabling us to "see" how the features in Finding 8 of the T-TEP report come to be. For instance, "active collaboration between physics departments and schools of education" is an outcome of attending to the development of certain habits of mind—thoughtful, knowledgeable, and intentional physics and science education faculty can value and leverage each other's expertise to cultivate the habits of mind of a physicist together with the habits of mind of a physics teacher. Siloed approaches (i.e., absence of collaboration) are unlikely to develop such habits. It is worth noting that DHAC does not imply that "active collaboration" will automatically yield such habits. As a matter of fact, several examples come to mind of cordial working relationships among physics and education faculty who approach physics teacher education as a sequential affair: first, physics content is learned in the physics department and then the candidate is shipped off to the teacher education program to "learn how to teach." Such a siloed approach is doomed to reproduce the status quo, with its well-documented shortcomings.

A second example comes from examining the role of the Learning Assistant (LA) program (The website 2022) within "early teaching experiences led by the physics department." A LA is a (usually undergraduate) student who facilitates group-worthy work in reformed STEM courses. The role of a LA is to help students learn by engaging a small group of students in questions designed to bring to the fore the group's ideas, so that they can make progress. It is not to explain the content or to solve homework problems or to troubleshoot lab equipment. In short, LAs are expected to practice Arnold Arons' dictum: "A person has two ears and one mouth. A teacher should use them in that proportion." (Arons) Enacting this is not easy even for teachers with many years of experience. How does a LA get to develop this habit? The answer comes from the tripartite nature of the LA experience.

The first part of the LA program is participation in a required LA Seminar, which is usually taught concurrently with the first time someone serves as a Learning Assistant. This seminar introduces important science education results about how students learn, the role of student ideas in instruction, the social threats that get in the way of equitable learning opportunities, ways to promote productive conversation in groups, etc. It also provides a low-stakes environment for LAs to observe or try out new things in the messiness of student interactions and reflect on their experiences. Over and over again. By minimizing the realm of instructional responsibility of a Learning Assistant (LAs, for instance, rarely develop group-worthy activities; they only facilitate their implementation), LAs get lots of opportunity to practice and practice again routines of interacting with peers, until such routines start to become habitual. The second part of the LA experience is a weekly meeting with the class instructor to discuss the specifics of that week's activities and, ideally, to go through them as students. This second component of the LA program instantiates what LAs are learning in the LA Seminar in the context of specific topics in physics. In this weekly meeting, LAs practice productive questions that are known to elicit student ideas in the particular domain, they role-play with each other, and they deepen their own conceptual understanding of the material of the unit. It is this content specificity that builds the LAs' Content Knowledge for Teaching (Phelps et al. 2020), at least for a subset of Tasks of Teaching (Etkina et al. 2018). The third and final component of the LA program is the classroom practice with real students. Through the lens of DHAC, the LA program, implemented as intended, can go a long way in shaping more sophisticated views of teaching and learning physics than many other prospective physics teachers exhibit.

In summary, DHAC is a helpful theoretical perspective in that it enables us to understand and improve features of PTEs. It also raises a slew of as yet unanswered questions.

4 Research Questions

Habits are the central construct of DHAC and the authors proposed a certain number of them, on the basis of their experience with teacher education and enhancement. However, which habits, from an ethnographic perspective, are the ones that effective teachers use, hone, and fall back on *in practice?* It would be very useful to observe physics master teachers in the classroom but also during lesson preparation and post-lesson reflection. Some habits, however, go beyond the school day and curricular design and enactment. Certain habits of maintenance and improvement have to do with professional decisions taken outside the school building and with professional actions that occur outside a teacher's contracted time. A methodology to tackle these thorny questions is required.

There is extant work on scientific habits of mind, including a survey to measure them (Calik and Coll 2012). For instance, Gauld (Gauld 2005) posits as scientific habits of mind open-mindedness, skepticism, rationality, objectivity, mistrust of arguments from authority, suspension of belief, and curiosity. How do such habits interact with physics-specific habits? Is a physics instantiation always a particular expression of such habits in the domain of physics or are there habits that are inherently physics-y? Surely, the processes of identifying and inculcating any physics-specific ways of thinking, acting, wanting, and orienting oneself are worth understanding.

There is an inherent challenge to engaging in this research. Namely, there is a need for crisp definitions of constructs. A quick search "scientific habits of mind" on Google Scholar shows that reference to habits of mind is often made in the context of scientific abilities (Etkina et al. 2010), epistemology (Young 2018), experimental skills (Wilcox and Lewandowski 2018), identity in physics (Randolph et al. 2022), science-religion interactions (Gauld 2005), etc. An instructive example comes from Ch. 12 *Habits of Mind* from Science For All Americans, a report of the American Association for the Advancement of Science (Rutherford and Ahlgren 1990), which was developed as part of Project 2061:

"The first part of the chapter focuses on four specific aspects of values and attitudes: the values inherent in science, mathematics, and technology; the social value of science and technology; the reinforcement of general social values; and people's attitudes toward their own ability to understand science and mathematics. The second part of the chapter focuses on skills related to computation and estimation, to manipulation and observation, to communication, and to critical response to arguments."

Habits of mind then are conflated with values, attitudes, self-efficacy, identity, and skills. How is this constellation of interdependent yet presumably distinct constructs organized? What are the interactions? What mediates which?

The reference to mathematics is also relevant in our case. Physics, perhaps more than any other science, requires mathematization and quantification. This, in turn, opens up questions about the interplay between physics habits and mathematics habits. (Boaler and Dweck 2016) Again, we must ask: since physicists use (and teach) mathematics in both similar and dissimilar ways to mathematicians (Redish 2021), are the habits physics teachers use about mathematics merely the intersection of habits or something different altogether? How should we be thinking about these constructs?

The DHAC paper presents a particular ordering of some of these concepts. However, as published, it does not surface adequately the role of non-cognitive aspects of habit formation. Social threats, resulting from individual microaggressions by others, personal theories of STEM intelligence, and systems of oppression, are bound to play pivotal roles in whether or not the individual will even start going down the path of habit formation. More research is needed in this area.

Then we have questions about the dynamics of habit development. (Butler 2020) Are habits that are relevant to physics teaching developed in the same way as other habits or are there certain idiosyncrasies? Are there ways to speed up the process of habit development? Given the constraints of designing and implementing worthwhile professional development (PD) to teachers, are there guiding principles around designing effective PD for habit formation or reinforcement (or perhaps, at a more basic level, (unproductive) habit abandonment)?

5 Discussion

Although the contexts in which physics teacher education and professional development occur vary by country (and in many cases by geographic region within large countries), the pivotal role that the professional preparation of physics educators plays for the physics enterprise writ large requires us to join forces in tackling research agenda associated with PTE. In this paper, we have touched on several foundational issues, in particular on the DHAC theoretical framework as a lens for understanding the features of thriving PTE programs. To use the framework constructively, the field is called to assume ownership of some research questions/research agenda such as those described in the previous section.

To better understand habits, the field would do well to understand practices in domains that are not cognate to physics, e.g., music or sports. Perhaps the field should also look to an improbable place—monastic practice in religious traditions in which such practice thrives. Spiritual disciplines depend crucially on practices that develop useful habits. Certain of these habits transcend religious affiliation. I am familiar with Buddhist monks in Northern California (Website of Emory University's Center for Contemplative Science and Compassion-Based Ethics 2022; Website of the Science for Monks and Nuns project 2022), for instance, who have had productive conversations with nearby Greek Orthodox Christian monks (Climacus 2019), certainly not about issues of religious dogma but rather about the daily routines and experiences of the practitioners. A thorough understanding of habits in service of physics teacher education will require a concerted effort, approaching the issues from all directions.

Acknowledgements My work on physics teacher education has been conducted in collaboration with others. I am deeply indebted to Eugenia Etkina and Lane Seeley for the critical role they have played in helping me develop and test my ideas. In addition, working with the following has shaped a lot of my thinking about teacher preparation in ways that I can easily pinpoint: Amany Abd El Aziz, Leanna Aker, Ruth Anderson, Leslie Atkins Elliott, Eric Banilower, Courtney Bell, Andrew Boudreaux, Sanlyn Buxner, Eleanor Close, Hunter Close, Costas Constantinou, Sally Crissman, Abby Daane, Kim Dean, Lezlie DeWater, Rich DiDio, Zeinab El-Naggar, Drew Gitomer, Catherine Good, Lisa Goodhew, Kara Gray, Bor Gregorcic, Paula Heron, Roger Hinrichs, Ted Hodapp, Chance Hoellwarth, Larry Horvath, Bryce Johnson, John Keller, Pamela Kraus, Sara Lacy, Augusto Macalalag, Lillian C. McDermott, David Meltzer, Joe Merlino, Donna Messina, Jim Minstrell, Matt Moelter, Fred Nelson, Valerie Otero, Nikos Papadouris, Geoffrey Phelps, Monica Plisch, Amy Robertson, Rachel Scherr, Brian Self, Peter Shaffer, Dave Smith, Sean Smith, Nancy Stauch, Roger Tobin, Kaylene Wakeman, Emily Walter, MaryMargaret Welch, Mark Windschitl, Michael Wittmann, and Rob Zisk. The writings of and long conversations with Arnold Arons, David Hammer, Marisa Michelini, and E.F. (Joe) Redish have guided my explorations in several areas in physics teaching and learning relevant to physics teacher education. Working on US-based and international programs involving thousands of K-12 teachers over more than 25 years has taught me the difference between ivory tower and classroom. Numerous unnamed colleagues have contributed to my ways of thinking about PTE, yet they do not show up here. That does not change the fact that I am deeply grateful for them.

References

Arons A, private communication

Boaler J, Dweck CS (2016) Mathematical mindsets: Unleashing students' potential through creative math, inspiring messages and innovative teaching (Jossey-Bass)

Butler LP (2020) Child Dev. Perspect. 14:34–40. https://doi.org/10.1111/cdep.12354

Calik M, Coll RK (2012) Int J Sci Ed 34(12):1909–1930. https://doi.org/10.1080/09500693.2012.685197

Climacus J (2019) The ladder of divine ascent ISBN-10: 179563524X

Etkina E, Karelina A, Ruibal-Villasenor M, Rosengrant D, Jordan R, Hmelo-Silver CE (2010) J Learn Sci 19(1):54–98. https://doi.org/10.1080/10508400903452876

Etkina E, Gregorcic B, Vokos S (2017) Phys Rev Phys Educ Res 13:010107

Etkina E, Gitomer D, Iaconangelo C, Phelps G, Seeley L, Vokos S (2018) Phys Rev Phys Ed Res 14:010127. https://doi.org/10.1103/PHYSREVPHYSEDUCRES.14.010127

Gauld CF (2005) Sci Educ 14:291–308. https://doi.org/10.1007/s11191-004-1997-x

GFO (2022) website https://getthefactsout.org/about/ retrieved on October 29

Magee N, Madden L, Richards A J, Bellino M, Chessler M (2022) Wherefore art thou, physics teacher? AAAS-ARISE blog post retrieved on October 22

May D (2021) "What we can do about the severe teacher shortage" ed J Docktor. APS Forum Educ Newsl, Fall 2021 (PDF), pp 3–5

Meltzer DE, Plisch M, Vokos S (2012) Transforming the preparation of physics teachers: a call to action. A Rep Task Force Teach Educ Phys (T-TEP) (American Physical Society, College Park, MD)

Phelps G, Gitomer DH, Iaconangelo CJ, Etkina E, Seeley L, Vokos S (2020) Educ Assmt 25(2):91–111. https://doi.org/10.1080/10627197.2020.1756256

Randolph J, Perry J, Donaldson J P, Rethman C, Erukhimova T 2022 Phys Rev Phys Ed Res 18, 020123 https://https://doi.org/10.1103/PhysRevPhysEducRes.18.020123

Redish EF (2021) The Phys Teach 59, 314 (2021); https://doi.org/10.1119/5.0021129, The Phys Teach 59, 397 (2021); https://doi.org/10.1119/5.0021244, The Phys Teach 59, 525 (2021); https://doi.org/10.1119/5.0021823, The Phys Teach 59, 599 (2021); https://doi.org/10.1119/5.0023066, The Phys Teach 59, 683 (2021); https://doi.org/10.1119/5.0025840, The Phys Teach 60, 18 (2022); https://doi.org/10.1119/5.0040055

Rutherford FJ, Ahlgren A (1990) Science for All Americans (New York : Oxford University Press), http://www.project2061.org/publications/sfaa/online/chap12.htm retrieved on October 29, 2022

The website of the learning assistant program at the university of colorado, Boulder https://www.colorado.edu/program/learningassistant/la-model retrieved on October 29, 2022

Website of emory university's center for contemplative science and Compassion-Based Ethics https://www.compassion.emory.edu/ retrieved on October 29, 2022

Website of the science for monks and nuns project http://www.scienceformonksandnuns.org/ retrieved on October 29, 2022

Wilcox BR, Lewandowski HJ (2018) Am. J. Phys. 86, 212; https://doi.org/10.1119/1.5009241

Young RF (2018) Habits of mind: how do we know what we know? ed A Phakiti, P De Costa, L Plonsky, S Starfield. Palgrave Handb Appl Linguist Res Methodol. Palgrave Macmillan, London. https://doi.org/10.1057/978-1-137-59900-1_2

Position Papers by Workgroup Leaders

The Development of Experimental Skills, the Role of Digital Technologies and Multimedia in Physics Teacher Education

Peter Demkanin and David Sands

Abstract The role of experimental skills in developing knowledge at secondary school is considered through the contributions presented in the working group. The position adopted here is that each of the natural sciences, physics, chemistry and biology, has slightly different epistemology and approaches to experimental observation. In physics, experiments are purpose-built to observe the phenomenon of interest, and that can only be done with a firm basis in knowledge as well as a range of experimental skills, which increasingly include computation and computer programming. Teaching physics with the use of digital technologies as well as teaching key concepts of digital technologies are among the major challenges for physics teachers and, thus, important topics of research and development in physics teachers' education. In the working group, different approaches to teacher training were discussed. First, we talked about how digital technologies can improve physics teaching and what needs to be added or changed in the physics curriculum. We also discussed what competencies a physics teacher needs to be able to use digital technologies in physics lessons meaningfully. Then we looked at what activities are necessary and effective in teacher training so that student teachers or teachers in training acquire these competencies. And finally, we looked for ways to assess these competencies. This article intends to summarise the working group's results and focus on possible research for the following years.

P. Demkanin (✉)
Faculty of Mathematics, Physics and Informatics, Comenius University Bratislava, Mlynska, Dolina F1, 842 48 Bratislava, Slovakia
e-mail: peter.demkanin@uniba.sk; peter.demkanin@fmph.uniba.sk

D. Sands
Independent Science Education Consultant, East Yorkshire, UK
e-mail: david.sands@physicseducationinternational.com

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2023

J. Borg Marks and P. Galea (eds.), *Physics Teacher Education*,
Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-44312-1_5

1 Introduction

During the COVID-19 pandemic, the International Research Group on Physics Education (Groupe International de Recherche sur l'Enseignement de la Physique, GIREP) organised multi-day online meetings instead of the annual conferences for 2020 and 2021 in order to maintain the fruitful and lively exchange of current research findings and field experiences known from the GIREP conferences even under adverse circumstances. During these online meetings, which lasted several days, discussions were held in thematic working groups on predefined topics. This paper summarises the results of the working groups "ICT and Multimedia in Teacher Education—Initial and Further Professional Development", "Experiments and Lab Work in Teacher Education", and "Preparing Teachers for TPACK and Lab Work".

Our aim was to identify the key directions in the utilisation of digital technologies in physics education and the education of physics teachers to meet various goals of physics education. The motivation for the workgroup was the realisation that the subject-specific use of digital technologies in physics education lacked coherence, which is essential for children to learn. Although teams developing hardware, software and activities have done a lot in this way, it often seems that the focus on particular issues obscures the overall ideas being developed. We sometimes do not see the wood for the trees. The workgroup participants, physics education scientists, practising physics teachers and educational digital technology solution developers are all involved in improving the physics education in their own countries and internationally.

Teaching physics with the use of digital technologies as well as teaching key concepts of digital technologies are among significant challenges for physics teachers and thus important topics. Physics teachers use technologies in their work and support pupils in using such technologies. So, physics teachers are professionals in teaching and learning, school physics content, and the technologies that enhance physics education. We tried to design the discussion and contribution presentations in a planned manner, defining the main subtopics: improvement of teaching methods, physics curriculum, physics teacher competencies, development of teachers, and testing teachers' competencies. We discussed different approaches to teacher training. First, we shortly talked about how digital technologies improve the teaching of physics and what needs to be added or changed to the physics curriculum to effectively utilise the possibilities offered by digital technologies.

Furthermore, we discussed which competencies a physics teacher needs to be able to use digital technologies in physics lessons in a meaningful way. Then we addressed the question of which activities are needed and are effective in teacher education programmes so that student-teachers or in-service teachers will acquire these competencies. And finally, we looked for ways we can "test" these competencies.

2 The Role of Experimental Skills

When people talk of scientists discovering a new planet or drug or anything else, there is an underlying assumption that science is a homogeneous activity. Yet, it is also common to talk of science as if it is a body of knowledge, whether in biology, chemistry or physics. Science is not a body of knowledge, nor is it homogeneous. It is a process of systematically testing theories or hypotheses against the evidence and knowledge so tested and validated is scientific knowledge. In so far as all the sciences engage in this activity, there is clearly some commonality, but deeper thought reveals crucial differences between them.

In classical biology, observation is a key element of the process. The natural world is often observed as it is. In physics, however, this is rarely, or one may say, never the case. Experiments have to be constructed, and the conditions created to make observations. Perhaps physics comes closest to observing nature as it is in astronomy, if we restrict ourselves to seeing parts of the universe that are not visible to the naked eye. However, astronomy is more than this, and we soon run into the essential problem of experimental physics: what do we measure? How do we measure it? And how do we use those measurements to make decisions about the physical world?

The issue is not trivial. Suppose we have an experiment running in a school laboratory to measure something well-known, for example, acceleration due to gravity or the refractive index of glass. We know from experience that most, if not all, students will judge the experiment on how close their measured value is to the "accepted" value, with no appreciation that the accepted value is itself an experimentally measured quantity. In truth, we can only judge a measurement in comparison with others, or we can place a limit on our confidence. This assigns uncertainty to our measurement and goes right to the heart of the measurement process. Unless we can assign an accurate uncertainty representing a reasonable estimate of our confidence in the result, we might be forced to conclude that the acceleration due to gravity or the refractive index changes from one part of the lab to another. But, of course, we could always disprove that simply by having someone else repeat the experiment. The experimental uncertainty should be large enough to incorporate our own measurement and that of others but needs to be evaluated systematically with skill and knowledge.

The whole concept of data analysis is difficult for students to grasp, even at university, let alone in schools. Yet, we must start somewhere. The contributions in this workgroup discussed different approaches to experimental physics.

3 Background

A lot of physics research outputs have direct relevance for the development of technologies, and at the same time, physics research utilises technologies within its research laboratories. Similarly, physics education has its firm place in science and technology education at all compulsory schooling levels and uses current technology. Intensive development of both main segments of this unity—technology and teaching–learning processes—yields many problems to solve and many questions worth exploring.

The progress of the use of digital technologies in science education is fully coherent with the results of research in The Learning Science, as presented by Sawyer (2014) and Tokuhama-Espinosa (2021). While in the second half of the twentieth century, the model of schooling was based on pre-assumptions, such as that knowledge is a collection of facts and procedures for how to solve problems, and the goal of schooling was to get these facts and procedures into the student's head, today's graduates work daily with complex concepts and need to learn to take responsibility for their own learning, need integrated and usable knowledge, rather than sets of decontextualised facts emphasised by instructions (Demkanin and Kováč 2019). The role of teachers in the acquisition framework was to know facts and procedures and to transmit them to students. In today's participatory approach, we foster pupils' participation in inquiry, even in formulating questions worth inquiry. The webinar proved that the direction of physics education is oriented to the development of children's abilities, not only to solve end-of-chapter textbook problems or apply predefined procedures planned by the author of a textbook or a teacher but also to actively and creatively plan, design, implement and evaluate inquiry. The current development of society and development of technology, well applied to physics education, clearly has the potential to improve physics education to a qualitatively higher level, and some best practices presented on these meetings proved that well-established technologies are already bringing an advantage to pupils, compared to schools where technologies are not used or are simply used in a manner which is not so wise.

4 Subject-Specific Digital Technologies and Multimedia in Physics Teacher Education

The utilisation of digital technologies has many dimensions. At these meetings, we focused on the preparation of physics teachers to wisely use subject-specific digital technologies and subject-specific competencies, as defined by DiKoLAN (Thoms et al. 2022; Becker et al. 2020; Girwidz et al. 2019; Thyssen et al. 2020) (Fig. 1).

To go deeper, we decided not to go to technologies and competencies for documentation, presentation, collaboration and information search, and focused on data acquisition, data processing, simulation and modelling, focusing on physics subject-specific technologies.

If we are talking about teachers in the plural, we are aware of the variability of teachers, the equipment they use, and the curriculum they follow. At the same time, we are looking at a pupil who usually has one physics teacher with one concrete teaching style, one educational environment, one set of equipment and even one type of personality. Within this vast variability, we decided to split the topic of

Fig. 1 Framework of digital competencies for teaching in science education (Thoms et al. 2022)

utilising digital technologies into four topics, as mentioned earlier. The first topic was focused on the question of which digital technologies can improve learning and teaching physics. The selection of technologies has the potential, and even a need, to update the curriculum. Teachers should be trained for the developed ability to adapt their teaching to the technology they use, in a manner such that pupils have a coherent educational environment fostering their abilities and knowledge related to physics, but also one which is in coherence with other school subjects. We put the competencies a physics teacher should have to use technologies in a meaningful way as a basis for the second topic. As a third topic, we identified the question of which activities are essential and which are optional for effective and efficient teacher education programmes. Some of such activities are important in pre-service teacher preparation, some in in-service teachers' lifelong education, and most of them are important in both. As the fourth issue, we selected the topics related to testing the teacher competencies related to the effective, wise use of subject-specific digital technologies. These four aspects of digital technology and multimedia in teacher education are discussed in the following sections.

4.1 *Which Subject-Specific Technologies Are Specifically Relevant and Positively Contribute to Physics Teaching and Learning?*

When discussing digital technologies in physics education at the secondary school level (ages 11–18), it seems appropriate to first focus on well-established technologies and research the possibilities to apply new, emerging technologies. In the webinar, remote experiments and robotic telescopes were presented as technologies quite well-established in some schools, so they are just in the middle of the well-established—emerging continuum. There are some teachers who regularly implement these technologies in their school curriculum, and it seems to be clear that there are only a few such schools. Students can make their own observations of selected stars, exoplanets, and other objects in the sky, using well-designed robotic telescopes [www.schoolobservatory.org]. Remote laboratories allow student-friendly and independent experimentation, even in expensive or dangerous experiments (Thoms and Girwidz 2017), but sometimes are also designed for simple experiments, which can be designed by equipment often available in schools.

As a well-established technology, we consider video measurement and sensors for measuring physical quantities. Video measurement has its firm roots in physics education. One of the participants of this meeting well mentioned that he started using technologies relevant to measuring motion and time some decades ago. D. Zollman said that his work in using ICT or multimedia to teach physics began in 1972. At that time, "multimedia" was Super-8 film loops. P. Demkanin also noted that his beginning to use video measurement goes back to the year 1992. An expensive video camera and costly frame-to-frame reply video player allowed measurement on a TV screen, just with a ruler, paper and pencil. An example of an enjoyable activity is the fall of a ball from the window on the school's third floor. The results were compared to the results of a model of fall with air drag, made in the software CMA Coach 3. Over the last decades, technological development changed the software and hardware to record video sequences and do measurements from the video. The idea is still the same—to measure the positions of objects in frames and look at the sampling frequency. Today's technology allows easy and intuitive taking of video sequences by the smartphone of a pupil or by a web camera. For data acquisition, two technologies were presented: Coach 7 and Tracker. Video measurement proved to be a well-established technology even during the pandemic when with online education, most students had no access to well-equipped school laboratories.

As we have already mentioned, the utilisation of sensors for the measurement of quantities at school is also a well-established technology. There are more producers of school data acquisition systems. At the webinar, only a short time was devoted to this topic. One of the reasons could be that this topic has been well-researched over the last two decades. The promising direction of research is focused on the use of sensors used by pupils of various ages, used directly in the hand of a pupil in a team of pupils. As the software is often well developed to be used intuitively, sensors, such as a sensor of temperature, force, light, or sound, have been proven as usable for the activities planned even by the pupils themselves, well scaffolded by the teacher, even from the age of 12. Low-cost and intuitive-use software environments offer the use of these technologies by children creatively.

As the next well-established technology used for physics education, we mention interactive animated models, applets and physlets. For most of us, interactive models allow us to adjust some of the parameters of the illustrated phenomenon and observe the phenomenon at such parameters. Some of the applets also present graphs or values. Using such applets as demonstrations or implantation into digital textbooks instead of static pictures or graphs is, without a doubt, beneficial. Another level of utilisation brings software environments allowing the pupils to prepare such interactive animated models. Some decades ago, as secondary school students, we were able to use graphical calculators to model physics phenomena and observe the results in the form of a graph. Now, in a much more straightforward, easy-to-use software environment, our students can model reality with the output in the form of animation. The use of these tools with pupils at lower secondary schools is still not researched deeply enough, but some experiences already prove that this use is promising.

Both the animated models designed by professionals and animated models designed by pupils themselves bring the possibility of multiple graphical representations of reality. By linking the different representations, learners can deepen the new learning content and connect what they have learned with existing knowledge.

When discussing ICT and multimedia technologies in physics education, we must not omit video sequence. A video sequence of a phenomenon in nature or a video sequence of a lab or terrain experiment is a suitable replacement for a photo or picture used in traditional textbooks or books of problems to be solved by students. Short, 4–8 min video sequences, well used in an interactive online course, were described as fruitful not only during COVID-19 distance education. Well-used video sequences in interactive lecture demonstrations are researched by D. Sokoloff (2022) and Teese et al. (2022).

Perspective technologies currently finding their place in physics curricula are 3D printing (Thoms et al. 2022) and augmented reality (Rosi et al. xxxx). Virtual and augmented reality has been pre-tested on students in the topic of kinematics. 3D visualisation of motion vectors (velocity and acceleration) for some motions in a headset or on a computer screen seems to be interesting for students. Virtual reality seems to be finding its place in physics education soon. Development of augmented reality to the level applicable for use in physics education seems to be quite difficult and will require a lot of hundreds of hours of development.

When discussing digital and multimedia technologies used in physics education, we can also mention datasheets of measured values. The most used are datasheets of sky objects or meteorology, often freely available on the web.

4.2 Which Competencies Do a Physics Teacher Need to Have to Use Digital Technologies in a Meaningful Way in Physics Lessons?

Digital technologies and physics curricula are interconnected, and they influence each other. As an example, we can mention the measurement of force. Force measurement is at the core of the physics curriculum at all levels, so we develop proper gadgets to force measurement. But suppose we use a force sensor allowing to have a sampling frequency of hundreds of hertz, connected to a gadget allowing automatic graph display and the possibility to work with the graph, everything user-friendly? In that case, we can quite easily adjust the curriculum and include real-time force measurements, including the slope of the graph or the area under the graph (e.g. impulse of force). What is also important is that these technologies allow for experiments planned by pupils, where a group of pupils can suggest the research question, hypothesis and apparatus. An example of such an experiment is in Figs. 2, 3 and 4.

To be able meaningfully to use the technologies to scaffold the development of the experimental skills of pupils, teachers should have developed TPACK (integrated technological, pedagogical, and content knowledge). A well-developed list of competencies a physics teacher should have developed is published in Thoms et al. (2022), Becker et al. (2020), Girwidz et al. (2019), Thyssen et al. (2020), Thoms and Girwidz (2017).

Fig. 2 Apparatus designed by a pupil

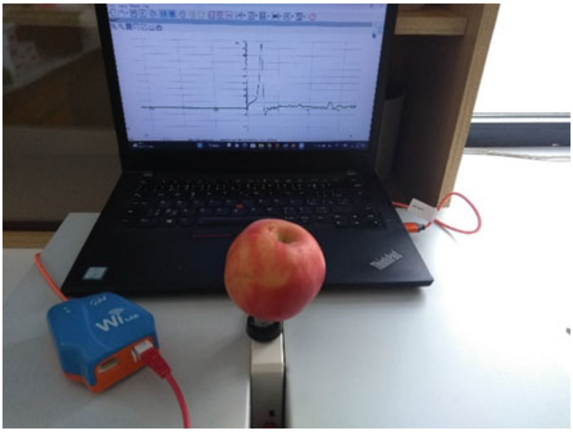
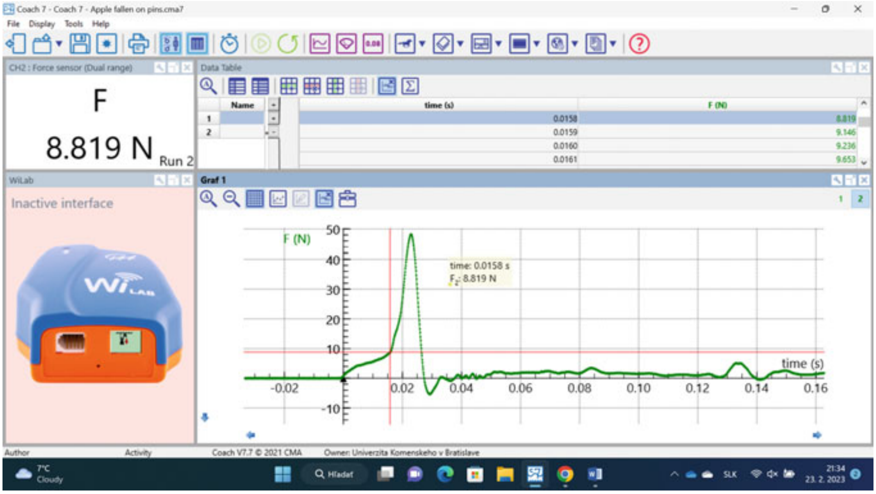


Fig. 3 Apple fallen down on a force sensor



F

8.819 N Run 2

time (s)	F (N)
0.0158	8.819
0.0159	9.146
0.0160	9.236
0.0161	9.653

Fig. 4 Raw data gained by a group of pupils well scaffolded by a teacher; experiment planned by pupils; apple fallen on pins on a force sensor

4.3 *What Are Effective Approaches to Be Used in Teacher Education to Acquire These Competencies?*

A lot of effective approaches have been indicated by the group around the project DiKoLAN (https://dikolan.de/) (C et al. xxxx). Here, we only present some ideas behind approaches in teacher education. Some decades ago, our students, future physics teachers, were taught that simpler facts and procedures should be learned first, followed by progressively more complex facts and procedures. The definitions of "simplicity" and "complexity" and the proper sequencing of material were mostly not determined by studying how children actually learn. The way to determine the success of schooling was to test students to see how many of these facts and procedures they have acquired (Sawyer 2014). The key findings of the Learning Science research imply that the most effective learning environments will have the following characteristics (Sawyer 2014):

- Customised learning. Each child receives a customised learning experience.
- Availability of diverse knowledge sources. Learners can acquire knowledge whenever they need it from a variety of sources: books, websites, and experts around the globe.
- Collaborative group learning. Students learn together as they work collaboratively on authentic, inquiry-oriented projects.
- Assessment for deeper understanding. Tests should evaluate the students' deeper conceptual understanding and the extent to which their knowledge is integrated, coherent, and contextualised.

The use of digital technologies is far inspired not only by the progress in computer science and by new digital technologies but also mainly by the progress in cognitive, educational and social psychology, by the 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 learning environments that result in deeper understanding, develop competencies and encourage creativity. It is well known that students learn deeper knowledge when engaging in activities related to everyday activities of daily life, as well as with professionals who work in a discipline. This is a benefit, even a necessary condition for an innovative, creative economy. Knowledge is not just a static mental structure inside the learner's head. Knowing is a process that involves a person, the tools and other people in the environment, so if we are discussing teaching, it is sometimes good to have in mind the learner—a teacher as a learner and a pupil as a learner. Some work trying to apply neurosciences to physics teacher preparation is in Demkanin and Novotna (2021), Demkanin (2018), Demkanin (2020), Velmovská et al. (2019), Tokuhama-Espinosa and Nouri (2020), Tokuhama-Espinosa (2019).

4.4 How Can We "Test" These Competencies?

Testing of competencies of university students, future physics teachers, in the level of development of competencies relevant to utilisation of subject-specific digital technologies at schools has its roots in the goals of physics education at the schools. This is applicable for formative as well as summative assessments, and it seems to be clear that this is still an open question. A lot has been done at Cito Institute for Educational Measurement (Smeets 2007) in the Netherlands, but more research is needed, especially in the development of subject-specific competencies related to the use of digital technologies in testing subject-specific competencies of pupils related to the use of digital technologies in physics inquiry.

5 Recommendations

Initial and further professional development of physics teachers is firmly associated with raising competencies for efficient use of empirical methods of cognition, such as observing, measuring and experimenting. Simulations and modelling also have a firm place in curricula. As in physics research, also in physics education, we foster the opinion of physics and science teachers, school leaders, decision-makers in education and the general public that digital tools are now an integral part of the teaching–learning environment. Wise and evidence-based use of such tools is the subject of research, which already offers reliable results.

The two GIREP multi-day meetings offer for discussion in the community of science education experts, experts in learning sciences, university teachers involved in physics teachers' professional development and physics teachers, the following partial results.

The professional development of physics teachers should include the following ideas:

- pupils need learning experiences that are relevant to their lives, where digital technologies, sensors, computer models and simulations are an integral part of it;
- empirical cognition of natural phenomena can be fostered by valid, reliable and precise measurements of physics quantities, often performed in a time longer than a usual lesson or shorter that can be measured by tools without data-logging;
- pupils need experience in all steps of the use of digital technologies, including the design of simple investigation;
- the use of digital technology should be adopted together with a holistic view of pupil development;
- well-adopted use of digital technologies fosters the understanding of scientific ideas, ideas about science, capabilities of pupils with gathering evidence, as well as scientific attitudes;
- development of technologies to be used in schools, as well as the selection of technologies to be used in schools, should be evidence-based;
- technologies used in schools should be an integral part of the educational environment; there are some programmes that avoid using technologies at lower grades, and the theoretical background for such programmes should be studied and analysed in view of the learning sciences;
- technologies and educational methods to use such technologies differ in formal, informal and unformal education;
- in formal education, technologies used at school should be reflected in all materials for pupils, such as textbooks (digital and printed), workbooks (digital and printed) and other digital sources adopted for use at the age level of pupils;
- clear progression towards the goals of physics education has clear steps, and neglected development at one age level can be difficult to develop later;
- formative and summative assessments have a crucial role in education, and this also applies to skills relevant to the use of digital technologies;
- teacher preparation should be well structured to allow focused development of particular aspects and transferrable general skills and attitudes.

Acknowledgements The work has been supported by the Scientific Grant Agency of the Ministry of Education, under the contract KEGA 013UK-4/2021, Methodical materials focused on the systematic development of critical thinking.

References

Becker S, Bruckermann T, Finger A, Huwer J, Kremser E, Meier M, Thoms L-J, Thyssen C, von Kotzebue L (2020) DiKoLAN – Digital Competencies for Teaching in Science Education. Workgroup Digital Core Competencies

Demkanin P, Novotna S (2021) Inted2021 proceedings 8710–16

Demkanin P (2018) J Balt Sci Educ 17:4–7

Demkanin P (2020) J Balt Sci Educ 19:860–863

Demkanin P, Kováč M (2019) AIP conf Proc. 2152 020002–2–7

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

Rosi T et al. J Phys: Conf Ser. 2297 012005

Sawyer RK (2014) The Cambridge handbook of the learning sciences. Cambridge: Cambridge University Press

Smeets PHH (2007) J Phys: Conf Ser 2297:01

Sokoloff DR (2022) Exploring multimedia to adapt interactive lecture demonstrations (ILDs) for home use. In: Borg Marks J, Galea P, Gatt S, Sands D (eds) Physics Teacher Education. Challenges in Physics Education. Springer, Cham. https://doi.org/10.1007/978-3-031-06193-6_1

Teese RB et al (2022) J Phys: Conf Ser. 2297 012004

Thoms L-J, Girwidz R (2017) Eur J Phys. 38 55301–55324

Thoms L-J et al (2022) J Phys: Conf Ser. 2297 012002

Thoms LJ, Hoyer C, Girwidz R (2022) A teacher training course on using digital media for acquisition, visualization and 3D printing of complex data and for fostering pupils' experimental skills. In Borg Marks J, Galea P, Gatt S, Sands D (eds) Physics Teacher Education. Challenges in Physics Education. Springer, Cham. https://doi.org/10.1007/978-3-031-06193-6_6

Thyssen C, Thoms L-J, Kremser E, Finger A, Huwer J, Becker S (2020) Digitale Innovationen und Kompetenzen in der Lehramtsausbildung, Beißwenger M, Bulizek B, Gryl I, Schacht F (eds) (Duisburg: Universitätsverlag Rhein-Ruhr) pp 77–98

Tokuhama-Espinosa T (2021) Bringing the neuroscience of learning to online teaching. Teachers College Press

Tokuhama-Espinosa T, Nouri A (2020) Evaluating what mind, brain, and education has taught us. Access: Contemporary issues in education 40:63–71. https://doi.org/10.46786/ac20.1386

Tokuhama-Espinosa T (2019) Five pillars of the mind: redesigning education to suit the brain. W. W. Norton & Company

Velmovská K, Kiss T, Trúsiková A (2019) Critical thinking and physics education. AIP Conference Proceedings, 030037

Approaches and Teaching Resources for Teacher Education in Quantum Physics

Marisa Michelini, Sergej Faletič, and Gesche Pospiech

Abstract Quantum physics as a consolidated theory and with increasing applications and visions from quantum technologies is gaining importance also as a subject in schools. Efforts are increasing to introduce quantum physics in high school throughout Europe. These efforts must be underpinned by stringent teacher education, as well as by general education and for orientation to vocational fields. Research shows that many teachers need special support because of the peculiarities of quantum physics and the inherent problems in teaching. In particular, finding suitable teaching resources—be it real or remote and virtual experiments, simulations, exploration environments, digital media or any other media—is central for teachers. These tools are important for education as well as for teacher education in this area. The WG3 during the online seminar in Malta 2021, therefore, discussed this aspect of teacher education as well as the general shaping of teacher education in this field. The results of discussion and a final position are summarized in this paper that gives guidelines for teacher education programs on quantum physics.

1 Introduction

Quantum physics is an established theory, despite questions which are still open regarding its foundations and some interpretational issues. Its applications are an integral part of the most modern technologies. In the first 50 years of quantum physics, on the one hand, the interpretational debate was ongoing and, on the other hand,

M. Michelini
URDF, DMIF, University of Udine, Udine, Italy
e-mail: marisa.michelini@uniud.it

S. Faletič (✉)
Faculty of Mathematics and Physics, University of Ljubljana, Ljubljana, Slovenia
e-mail: sergej.faletic@fmf.uni-lj.si

G. Pospiech
Department of Physics, TU Dresden, 01062 Dresden, Germany
e-mail: gesche.pospiech@tu-dresden.de

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2023

J. Borg Marks and P. Galea (eds.), *Physics Teacher Education*,
Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-44312-1_6

applications such as, for example, the LASER, the transistor, applications of superconductivity and semiconductors were found and exploited. Since then, in the last 30 years, immense advances in every respect have been made, concerning the theoretical foundations as well as technological application in the so-called second quantum revolution: the quantum computer, quantum cryptography and quantum sensors and so on. This development led to the establishment of a vast research program, the European Quantum Flagship (https://qt.eu/). The developing technologies create an increasing demand for training in the subject: from basic training in schools, especially secondary schools, to training for a technical workforce with special needs of skill (Müller and Greinert 2021). Teaching quantum physics, however, often covering non-intuitive topics, requires tools that foster conceptual learning as well as developing skills in application and transfer. In this respect, physics teachers have a relevant role and responsibilities, and need to be educated properly. This position paper, which results from a 3-day discussion in Work Group 3—Teacher education in quantum physics—during the GIREP-Webinar 2021 in Malta, aims at describing basic requirements and strategies for an effective teacher education focusing on approaches and tools available to support student learning with respect to quantum physics across Europe. This contribution completes the position papers of the foundation of the GIREP community on teaching/learning quantum physics (Michelini et al. 2021a) and on teacher education in quantum physics from the GIREP online seminar held in Malta 2020 (Michelini et al. 2021b).

1.1 Topics of the Workgroup

The workgroup discussion we present here was based on research on effective teacher education or professional development as well as on research on teaching and learning quantum physics (see e.g. Adorno et al. 2017; Emigh et al. 2020; Fernandes et al 2020; Michelini et al. 2013). The focus was on enhancing the pedagogical content knowledge (PCK) of (future) teachers. The pivotal issues that were addressed are summarized in the following questions:

- What needs did teachers highlight in quantum physics training intervention modules regarding teaching aids?
- What types of instructional supports were most effective and/or liked by the teachers?
- What empirical research results exist concerning the effectiveness of teacher training with respect to which criteria?

There are different research-based approaches to educational paths in quantum physics with related learning results (Michelini and Stefanel 2021a). As research literature has shown how educational tools can be useful in an approach to concepts as well as in their consolidation, such tools are important for teacher education on the topic (Bitzenbauer 2021). In addition, new possibilities such as the Open Educational Resources (OER) should be considered (Baas et al. 2019).

1.2 The Workgroup Discussion

In this section, we describe briefly how the work was prepared and conducted. The participants sent their contributions before the online seminar and had the opportunity to read each other's contributions in advance. On the first day, each participant shortly highlighted the most important aspects of his/her work in teacher education in quantum physics with regard to teaching resources, methods and educational paths. In order to have a fruitful discussion, we assumed that the contributions have been read and asked for a flash presentation of the main points of each contribution. On the second day, the key issues to be discussed were summarized in the following questions, asking for research-based answers:

1. Teaching resources for teacher education
    - (a) What types of teaching resources are most effective and are valued by the teacher and why?
    - (b) Which specific tools (such as, e.g. experiments or simulations) have proven effective in the teaching of quantum physics and in which way did they prove effective?
    - (c) What needs have teachers highlighted in the training modules on quantum physics with regard to teaching resources?
2. Shaping teacher education in quantum physics:
    - (a) What kind of teacher education or professional development produces the development of concepts, instruments and methods that allow them to build learning environments?
    - (b) How should a teacher education activity be conducted to produce the competence in the integration of quantum physics content and teaching resources for building a good teaching–learning environment?

On the basis of the discussion of the second day, the essential points were defined and described on the third day and presented by the workgroup leaders in the closing session. The results then led to the position presented below.

2 Results of the Discussion

The participants agreed that in teacher preparation the focus should lie on fundamental basic concepts, on the universal ideas, and not on a very specific teaching plan, because the environment of different schools in different countries and the background of students is likely to vary widely. But the universal concepts are at the heart of quantum physics teaching and can be addressed and approached in different ways (Michelini and Stefanel 2021a, 2022). In teacher education as well as in student education, it is relevant for the global view on the theory to ensure the coherence of the rationale in the given proposal in view of the basic concepts themselves. This basic idea underpins the following more detailed aspects.

2.1 Teaching Resources for Teacher Education

In the participants' contributions, many different resources were addressed. During the discussion, additional aspects were raised and supplements made. The resources are at the core of the discussion, intended to link the phenomena to basic properties of quantum physics. The resources can be divided into several categories: experimental resources, interactive (digital) media, classical media such as textbooks or tutorials (even if presented in digital form), exchange with peers and researchers.

Experimental resources. Even if it is difficult to implement real quantum experiments, it was stressed that experiments are important for credibility and for motivation or triggering curiosity of students. Many teachers, therefore, value them highly and want to know which experiments might be possible to use at school (Bitzenbauer 2021). However, at most schools, only laboratory apparatus for basic experiments such as optics and electron diffraction, absorption spectrometer or photoemission apparatus are available that lead more to atomic physics than to modern approaches via quantum optics. The photoelectric effect was regarded as a historic experiment whose position as part of a quantum physics curriculum at high school should be reconsidered. On the other hand, in an approach via quantum optics, there are experiments that can mostly only be done as analogy experiments. Relevant experiments such as the Hong-Mandel-Ou experiment or the existence of single photon states can only be described or treated with help of simulations. From the perspective of a phenomenology-based approach, proposals based on optical polarization (analogical experiments) or spin (thought experiments with Stern-Gerlach-apparatus) coupled with simulations have given evidence of effectiveness for learning basic concepts (Michelini and Stefanel 2021b; Pospiech 1999; Freericks et al. 2019; Bondani 2021). On the whole, this topic was only very shortly touched upon.

Interactive media. Interactive simulations like Quvis or Phet allow for focusing on specific details or highlight differences between quantum physics and classical physics. They can also help to bridge between experiment and theory. Frequently named topics for simulations include the Stern-Gerlach-experiment with variations, Bell experiments or the double slit experiment in different variations (which way information, delayed choice, quantum eraser,..). The double slit experiment can also be treated with a simulation of a Michelson or a Mach–Zehnder interferometer. In this way, the real experiments *that* are perhaps not possible at school can be discussed with help of (interactive) simulations. Other open software environment for simulation as JQM had the role of connecting macroscopic phenomenology with the microworld of single photon behavior (Michelini et al. 2002, 2010, 2016). Another useful tool in this respect is the QuVis project (Michelini et al. 2016).

Perhaps during a teacher education program teachers can even create their own simulations in order to reach a deeper understanding both of content and of learning process. Possible tools would be Python or v-Python. This language is well suited for simulations and is quite widely used for learning programming in computer engineering courses. Meanwhile, Python is sometimes even used at schools.

A topic gaining more and more attention in physics education in general, but especially in quantum physics, where the abstract concepts should be visualized, is gamification, above all interactive games. In games, the quantum rules are incorporated in the rules of the game (www.qplaylearn.com or https://www.scienceathome.org/games/quantum-moves-2/; Chiofalo et al. 2022). Students (and teachers) can get acquainted with the quantum phenomena in playing and thus explore them thoroughly and gain experience. This feature provides an experiment-like environment to enact rules. In gaming, teachers (and students) get more familiar with the quantum world and might prepare a more thorough or formal treatment. Such games promote playing with the concepts and exploring their meaning with the support of additional materials (Chiofalo et al. 2022).

Classical media. Teachers that are just learning how to implement quantum physics in their teaching–learning activities would need for their reference a suitable textbook and reliable materials that might be provided in a database (which is an intended result of the EU-quantum flagship).

As active learning has proven to be successful in quantum physics, teachers should also be provided with tutorials, working them through either by themselves or during education programs and be able to use them to analyze conceptual learning difficulties (nodes). Validated questionnaires are also useful for teachers to get insight into the learners' progress and thoughts.

Exchange with peers and experts. For many teachers, teaching quantum physics and more so applications from quantum technology is a quite new field. Therefore, they first have to get acquainted with the content, especially if they are getting to know a new approach.

In the first phase—the acquisition of the content and a teaching proposal—expert videos or an expert discussion platform could be helpful where teachers can ask questions or discuss their own or given materials. Furthermore, they can get background information especially in the case of recent or up-to-date applications. This is important since students may ask questions concerning the concrete realization of experiments or the specific functioning of applications. Besides this expert level, a peer (teacher) discussion platform would be helpful to concretely discuss teaching materials and methods and exchange experiences in the classroom.

In optimizing teaching materials or the design of the teaching–learning-activities, an exchange on every level will be helpful: communication with peers for direct interaction, with physicists to check, for example, the admissibility of reductions or to get additional information, and with physics education researchers for checking with respect to learning processes or evaluation. In particular, the education researchers who have developed specific proposals are the main referents of teachers: they have in fact thoroughly studied the theory, developed and validated the proposal, carefully taking learning processes into account.

Implementation of resources in teacher education. The participants agreed that the teaching resources are efficient when integrated into a learning module that supplements these tools with other materials (videos, text, activities, etc.) that are properly designed to achieve specific learning goals. All the proposed resources have to be given a didactical meaning and have to be coherent with the presented proposal for high school and its objectives. The role of (real) experiments, videos showing experiments or simulations for the learning path of students, especially, has to be discussed explicitly in a teacher education program. The materials should serve for inducing active learning, for example by means of IBL or ISLE approaches, and should be tried by the teachers themselves, also as learners (Etkina et al. 2019).

Concrete applications from quantum technologies, such as, for example, quantum cryptography, are used as central features of some approaches to increase motivation—for students and teachers alike. On the other hand, it also means that later on the concepts have to be transferred to other applications. Therefore, the used resources have to mirror this. They have to be specific for the context and also allow for transfer to other applications because teachers and students alike have to grasp the taught concepts as universal.

The developed resources have to be adaptable by the individual teacher as far as possible, for example worksheets or tutorials, or they have to be flexible or interactive as for example, simulations. During the teacher education program, the teachers have to be made familiar with the opportunities of the different resources and should develop awareness of how to choose, modify and implement them.

2.2 Characteristics of a Successful Teacher Education Program

In this section, we address question 2 from above: What kind of teacher education or professional development produces the development of concepts, instruments and methods that allow teachers to build own learning environments?

In the discussion, it was stressed that shaping a teacher education program requires a clear research-based structure and formative activities. Also, the teacher educators need to have in mind some appropriate learning goals in high school and the responsibility of the school to provide culture-based education. However, as the precise learning goals may not be known or may change with time the teachers have to have a broad education. This implies that the teachers should be enabled to give the students the basic ideas of quantum physics.

In the following, we will discuss what are the essential elements that must be included in a teacher education program to make it effective, in the sense that teachers implement it in their teaching.

Focus on conceptual ideas. An aspect often stressed was that the teachers have first to be clear of the conceptual ideas of quantum physics among them mainly superposition, entanglement or the measuring process before going into details of formalization and mathematical description. These define the central content that should be assimilated by the teachers, independently of the specific chosen approach.

A suitable approach could be the Dirac approach with discrete quantities such as spin, modeled by polarization of light (Michelini and Stefanel 2022; Pospiech 1999).

It was remarked that just the basic formal university education does not enable the future teacher to carry out a course for his or her students (Pospiech and Schöne 2014). On the whole, in quantum physics, the formalism has almost a conceptual role. Therefore it cannot be ignored and has to be integrated adequately. The degree of formalization also depends on the starting level of the teachers, their goals and their future school teaching. Sometimes perhaps even the non-mathematical introduction, e.g. quantum games, is appropriate, adjusted to the teachers' needs and in some circumstances might be sufficient. In other cases, a simplified mathematics, for example with a visual presentation of the solutions of the Schrödinger equation or a suitable iconography like the Dirac notation can be introduced. Also, many phenomena can be described with high school algebra, geometry, trigonometry or work with arrows. To which extent, these mathematical elements can be used at high school, the teachers have to decide depending on the situation. Taken together a teacher education program should concentrate on material that could in principle be mastered by (gifted) high school students and would fit in with their level in mathematics.

There was some agreement that the teacher education program should be rooted in phenomena. Which phenomena, out of the numerous possibilities, would be suitable depends on the actual situation, but one could think of quantum devices (LED, SSD,..), magnetism (spin, MRT,..), light (classical light and photons) or basic phenomena (interference, Mach–Zehnder-Interferometer,..). One could also start from a suitable application in quantum technology such as quantum gates in a quantum computer and building on this introduce the transformations in Hilbert space of quantum physics.

Practical proposals and exercises. There are some basic elements of effective design of a teacher education program: it should take into account the teachers' curricular needs and provide them with the appropriate resources. Furthermore, own activities and experiences are important (Rogers et al. 2007). This implies that these proposals define the approach, the logical educational path and the methodology with the concrete teaching resources. In order to be realizable they should be validated by education research.

How a teacher can better implement a proposal in his/her school activity is under discussion: some positions preferred ready-made proposals, others pleaded for semi-ready materials that teachers could easily adapt to their needs, their teaching styles, their preferences, knowledge and skills. With the help of ready-made proposals, possible difficulties in content knowledge and pedagogical content knowledge can be circumvented in teaching, especially as long as teachers have not a big experience or if there is no teaching tradition on quantum physics in their country.

It remained also an open question if the teachers should become familiar with several approaches or only one approach in depth, together with an educational path and some teaching resources. The tendency, however, was to focus on one approach and only to mention other approaches in order to have sufficient time for the teachers to get confident with at least one approach. But the teachers should know that the core conceptual ideas can be taught also with other approaches.

Learning by exchange of thoughts. The general experience indicated that fostering exchange and discussions among colleagues would enhance the effect of teacher education programs. This method, perhaps implemented as a think-pair-share or explicit peer discussion, serves as a scaffolding. The discussion among colleagues might also help to overcome anxieties in explaining quantum physics to students, amplify the metacognitive knowledge and reduce cognitive load. It was mentioned that especially with the two-state approach, which allows for analogic experiments, discussion among learners are enhanced. Teachers can learn by exchanging their experiences about teaching, use of resources in school or their thoughts about the subject matter. Research shows that peer instruction is suitable to increase not only the content knowledge of physics/science teacher students but also their self-efficacy.

Worthy of discussion is also the learning effects of a conscious choice of words and using specified language (e.g. speaking about "photons" or about "quantum objects"?) or how to introduce central concepts like the photon (e.g. What is meant by "single photon states"?).

Support by researchers. Based on a proposed teaching–learning environment, the teacher should develop an own intervention, implement it and evaluate it. During this process, he/she needs support in the first line by physics education researchers who have developed the proposal, are competent in the field, can analyze the learning process and perform the monitoring. Well-prepared physicists can answer specific questions. This support for teachers in the design phase and the school implementation phase might include microteaching, the discussion of the proposal with peers and experts, how to design tutorials and how to evaluate the implementation meaningfully.

Furthermore, the results of an Italian survey (Sutrini et al. 2022) have to be considered. It showed that only a small fraction of teachers after the program developed didactic interventions based on the material received. In fact, from the results of the survey, a criticality in the realizations of the activities into classrooms clearly emerged, which has its roots in the lack of integration of this phase in the proposal. The adaptation into the classroom of the activities treated during the program is one of the most critical problems to manage and probably to be set during the planning of the course.

Therefore, to achieve the competence in the integration of quantum physics content and teaching resources for building a good proposal, in addition to defining the approach, it is also necessary to include the didactic transposition, which cannot be left to the teacher alone. But even more than that, in addition to specific elements of disciplinary teaching (methodologies and educational paths validated by education research), assistance in proposing at school the contents learned during the first part of the program must also necessarily be included during the planning phase of the professional development activity. It is, in fact, necessary to extend development to classroom experimentation, even if partial, but in which the teacher gets involved, perhaps asking for help for coherent planning.

One aspect in the development of an own intervention is to stimulate ones creativity and thus to gain self-efficacy. This can be promoted in that, for example, the teachers are enabled to create their own quantum games, at first with the guidance of experts. In order to do so they have to be clear what are the quantum rules, what is the meaning of the quantum concepts and how to translate them in to the rules of the game. This requires first some theoretical work but might deepen the understanding and motivate the teachers in the end.

Additional aspects. It was discussed to what extent the teachers should perceive quantum physics as something completely different from classical physics, compare classical physics with quantum physics or stress the overlap of some terms and notions and create a transition, e.g. by the sum-over-paths approach. Concerning this point, there were different positions about the most suitable way to teach the relation of classical and quantum physics or make a sharp cut.

However, there was some agreement that one could use transferable skills. Among them is above all an understanding of the role of models. This would also ensure that the students do not need to learn everything at the same time. They can learn beforehand that physical phenomena are described by models which is true throughout physics. The corresponding metacognitive activities would require them to think about the nature of models and at the same time also about the nature of physics. Such philosophical aspects encouraging the students to reflect upon the nature of physics are also important in teacher education. Research indicates that the nature of quantum physics itself fosters the development of adequate views about the nature of science in students (Stadermann and Goedhart 2020). Even students that did not perform well on assessments of their content knowledge about quantum physics performed well on the questionnaire about the nature of science.

Furthermore, teachers should know the most common alternative conceptions and learning difficulties in quantum physics and be aware of affective issues such as motivation, self-efficacy etc. in learning.

3 Position

In the discussion workshop, three very important guidelines emerged for teacher education (Sutrini et al. 2022; Pallotta 2022).

1. Teachers should always have in mind the intended, the possible and the realized learning outcomes of their teaching/learning activities.
2. Teachers must experience themselves a coherent educational path on quantum physics with appropriate teaching/learning activities including all the tools they plan to use in their implementation.
3. Teachers should design or redesign a given proposal or develop their own teaching/learning sequence during the teacher education program while they can be assisted by physics education researchers in the field.

Each of the above guidelines incorporates several other points that will be discussed in the following subsections.

3.1 Learning Goals

In a teacher education program, it is important that teachers should define possible learning goals for their students and reflect on them also in the context of culture-based education. In some countries, the goals are at least partially determined by the curriculum and/or the final exam. In other countries, quantum physics is not (yet) in the main curriculum and teachers can choose their own goals. These can have a wide range: should students merely recognize quantum phenomena, should they be able to recite the basic rules of quantum physics, should they be able to use the rules to explain phenomena, predict outcomes of experiments or calculate results for specific cases, or should they at least in part build the quantum model themselves? Should they be aware of interpretational debates and be able to discuss the philosophical and cultural implications of the existence of quantum physics?

A teacher education program in quantum physics should aim to address the fundamental concepts of state, property, superposition, indeterminacy or uncertainty, measurement and entanglement. Additionally, the non-existence of trajectories and state evolution were mentioned as being important for more traditionally taught courses covering, for example, atomic physics.

When setting the educational proposals, affective aspects of learning should be considered. What motivates students? Is it the mere thirst for knowledge, or is it practical applications such as quantum computing and quantum cryptography? Motivating questions can be used to pique students' interest such as: Why is a quantum encryption safer than a classical one? There is evidence that experiments with interesting outcomes are motivating. Teacher educators should be aware of various motivational techniques and help teachers choose the appropriate ones depending on their goals and the corresponding teaching/learning sequence.

Any teacher education program should include an activity where teachers must reflect on the appropriate choice and use of available resources, be it in an already existing teaching/learning sequence or in one they are building themselves. They may start from the sequence that they should have experienced in the program and carefully consider how the activities and resources in the sequence serve to achieve the goals set for students. Then, they should consider their own goals for their students, which may not align perfectly with the goals of the experienced sequence, and reflect on how the activities can be modified to serve their goals. They should find a balance between concrete contexts or applications and the universal character of quantum concepts as to be taught in culture-based physics education.

3.2 Experiencing a Proposal

Many different resources to support the teaching of quantum physics in high school were discussed. Some resources are already entirely developed proposals, teaching/learning sequences or modules and form coherent approaches with their own goals, teaching strategies, and tools. Some resources are just stand-alone tools such as interactive experiments, simulations or games that can be used in a course to develop quantum concepts and be adopted flexibly.

The challenge for teacher education is to educate teachers who are competent and confident in meaningfully integrating the teaching resources into an (own) teaching/learning sequence and implement it in class. For this purpose, it is paramount that the goals of the sequence, the tools used and the teaching methodology (including student activities) are aligned.

A teacher education program should be structured in a way that the teachers experience first-hand a coherent teaching/learning sequence as learners and go through the same activities that they will later have to implement in the classroom. It is probably tempting for teachers to just implement the approach in school, but this usually does not produce the desired results. Any coherent teaching/learning sequence has its own goals which may not align perfectly with the goals of the teacher for their students. Therefore, in a teacher education program, the teacher should reconstruct the sequence in light of their own goals and reflect on the reasons why a particular tool has been used in a particular way and whether this way is still appropriate for their own goals, preferences and style of teaching. To be able to integrate a tool in a meaningful way in their own teaching, the teacher must have the opportunity to experience the tool and explore its features. This metacognition on the experienced tools belonging to the selected sequence should be done in discussion with the researchers and/or those responsible for the teacher education program. Its goal is for the teachers to gain confidence in the material and the educational logic of the sequence working of the approach, be aware of its potential and requirements, be flexible regarding learning outcomes, and be able to handle a wide range of potential questions or discussion topics from students.

3.3 Planning a Teacher Education Program

After experiencing a coherent teaching/learning sequence, a teacher education program should require that teachers plan their own teaching/learning sequence or educational path. It is perfectly acceptable to simply adapt the experienced sequence to one’s own goals. Teachers should reconstruct their own sequence and go through the reflective steps as explained in Sect. 3.2 to gain familiarity with the sequence, its goals and its strategies for achieving the goals, even if ultimately only minor changes are made. The teacher education program should allow enough time for teachers to carefully plan their sequence for intervention. Teachers should develop detailed materials for the included activities (test, inquiry questions, tools and ways to implement it, learning monitoring materials) before implementation of their planned sequence. Then, their proposal should be discussed with the researchers with respect to their own goals. The researcher can offer further advice and discuss difficulties that teachers may have experienced planning the course or might expect during implementation. An additional step of discussion with peers can be added before the discussion with the researcher.

Alternatively, the teacher might start from a pre-developed teaching/learning sequence for their implementation. In this case, to assist them in choosing the appropriate sequence, a database should be built that would include all the metadata necessary for determining the appropriateness of the sequence for their own preferences and the audience: level, country, type of school, curricular reference, if any, goals, methods, context, etc. This way it would be easier for the teacher, but research shows that a reconstruction of the activities for classroom work in a coherent path by the teachers themselves produces confidence and flexibility in its implementation.

Two more aspects of creating a teaching/learning sequence and potentially choosing the sample sequence have been emphasized: language, including mathematics, and teaching methods.

Language is extremely important in quantum physics. Terms are new, or are used differently from classical physics. So it is important to choose the terminology carefully and be consistent in its application. But equally importantly, the level of desired mathematics needs to be taken into account. There are numerous teaching/learning sequences that use standard quantum physics notation, such as commonly seen in the context of the Schrödinger equation or the Dirac notation. But there are also some teaching/learning sequences that introduce their own notation or other symbolic representation. These representations use histograms of probabilities instead of complex coefficients (for example two columns representing the probabilities of getting one eigenstate or the other upon measurement) or Feynman-style phasors to indicate the phase of the complex coefficients. Research into advantages or disadvantages of such representations is still very fragmented, but there is consensus that the Dirac notation can generally be adopted by students of all levels. The choice of the level of mathematics is strongly dependent on the students, their interests and skills and the goals. If calculation is among the goals, then a symbolic pictorial notation might not be a good choice. On the other hand, if conceptual understanding is the main goal, including a quantitative notation might be an unnecessary overburden for students.

The interplay between mathematics and physics plays a special role in quantum physics. While in classical physics, mathematical formalism is usually derived from other types of representations (diagrammatical, pictorial), in quantum physics, the mathematics takes on the conceptual role. All different interpretations of quantum physics are so far on similar footing as long as they are all consistent with the mathematical formalism.

The teaching method is very important. While there is strong evidential support that active engagement methods are superior to traditional passive methods (Hake 1998), the teaching method and style should be tailored to the teacher. This is also one of the reasons why teachers have to reconstruct even an already existing teaching/learning sequence. Moreover, there are different active engagement methods available (Etkina et al. 2019; McDermott et al. 1998; Mazur 1997; Buongiorno et al 2021). However, changing the method from what is usually done in class only for the course on quantum physics might not be a good idea. Ideally, the teachers should be at least acquainted with the various methods so that they can orient themselves in choosing the one that best suits them and their goals. Supposedly, this should have been addressed in other parts of the teacher education programs. If the teachers are unfamiliar with a particular teaching method, the sample sequence can still be adapted to their own method. This should be done with the help of the education researcher or responsible of the teacher education program in the phase of reflection on the experienced sequence and during the preparation of one's own sequence. Many activities used in one active engagement method can be adapted to be used in a different active engagement method and even in more frontal teaching styles, if teachers are not familiar with any active engagement method.

3.4 Additional Points

Approaches to teaching quantum physics have different strengths and weaknesses. These often depend also on the chosen context, such as position, spin, or polarization. A position approach lends itself naturally to the discussion of potential, tunneling and time evolution, while spin and polarization contexts mostly do not include time evolution. On the other hand, the polarization approach lends itself naturally to the introduction of vector notation in the simplest possible way. There are numerous other subtle differences between what can naturally emerge in one context but would require significant effort in another. It could be the goal of a future discussion workshop or an international project to identify the strengths and weaknesses of each context and approach.

Likewise, teaching resources also have strengths and weaknesses. For example, the very good PhET simulation Quantum wave interference (https://phet.colorado.edu/en/simulations/quantum-wave-interference) has the option to see that a single particle hits on the screen, but it does not have the option to hide the wave pattern between the source and the target. Thus, it can be used for visualization after the wave model has been developed, but it cannot be used to develop the wave model. This is why teachers should have the opportunity to explore the tools that they want to use to experience their strengths and limitations.

To gauge the efficiency of the teacher education program, evaluation of teachers' and students' learning should be implemented. Evaluation of teachers' learning is needed to make sure that the teachers indeed learn what has been discussed in the program. Evaluation of students' learning is needed to make sure that the material taught can indeed be efficiently used in school with students. Teacher evaluation usually relies on evaluating the preparation of their teaching/learning sequence. Since the prepared sequence should be iterated with the researchers the iteration can be used for evaluation. Additional questionnaires to test teachers' understanding of the concepts of quantum physics are often employed. Students' evaluation depends on the goals of the course for students. Sometimes it takes the form of an exam, sometimes a conceptual questionnaire, sometimes a concept map. If tutorials or other worksheets are used, then responses on the worksheets can also be used for evaluation purposes.

Acknowledgements We thank the following colleagues for contributing and participating to the discussion of the WG3 in Malta online seminar 2021 (in alphabetical order): Maria Bondani, Maria Luisa Chiofalo, James Feericks, Nilüfer Didiş Körhasan, Russell Mizzi, Filippo Pallotta, Henk Pol, Kirsten Stadermann, Stamatis Vokos.

References

Adorno DP, Fazio C, Pizzolato N, Battaglia OR (2017) Training pre-service and in-service secondary school teachers: analysis of changes in perceptions about quantum physics concepts and NoS views

Baas M, Admiraal WF, Berg EV (2019) Teachers' adoption of open educational resources in higher education. J Interact Media Educ 9(1):1–11. https://doi.org/10.5334/jime.510

Bitzenbauer P (2021) Practitioners' views on new teaching material for introducing quantum optics in secondary schools. Phys Educ 56(5):055008

Bondani M (2021) Single-photon Mach-Zehnder interferometry for high schools. J Phys: Conf Ser 1929:012055. https://doi.org/10.1088/1742-6596/1929/1/01205

Buongiorno D, et al (2021) Discipline-based educational research to improve active learning at university. In: Levrini O, Tasquier G, Amin TG, Branchetti L, Levin M (eds) Engaging with contemporary challenges through science education research. Contributions from science education research, vol 9. Springer, Cham. https://doi.org/10.1007/978-3-030-74490-8_24

Chiofalo ML, Foti C, Michelini M, Santi L, Stefanel A (2022) Games for teaching/learning quantum mechanics: a pilot study with high-school students. Educ Sci 12:446. https://doi.org/10.3390/educsci12070446

Emigh PJ, Gire E, Manogue CA, Passante G, Shaffer PS (2020) Research-based quantum instruction: paradigms and tutorials

Etkina E, Brookes DT, Planinsic G (2019) Investigative science learning environment. Morgan & Claypool Publishers, San Rafael, CA

Fernandes GWR, Rodrigues AM, Ferreira CA (2020) Professional development and use of digital technologies by science teachers: a review of theoretical frameworks. Res Sci Educ 50:673–708. https://doi.org/10.1007/s11165-018-9707-x

Freericks JK, Cutler D, Kruse A, Vieira LB (2019) Teaching quantum mechanics to over 28,000 nonscientists. Phys Teach 57:326–329

Hake RR (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

Kohnle A, et al (2018) QuVis: the quantum mechanics visualization project

Mazur E (1997) Peer instruction: a user's manual. Prentice–Hall, Upper Saddle River, NJ

McDermott LC, Schaffer PS, The University of Washington PERG (1998) Tutorials in introductory physics. Prentice–Hall, Upper Saddle River, NJ

Michelini M, Pospiech G, Faletič S, Stefanel A (2021a) GIREP Community on teaching/learning quantum physics in secondary school. J Phys: Conf Ser 1929(1):012044. https://doi.org/10.1088/1742-6596/1929/1/012044

Michelini M, Faletic S, Pospiech G (2021b) Work group 3 position paper: teacher education and teaching/learning quantum physics. J Phys: Conf Ser 2297(1):012015. https://doi.org/10.1088/1742-6596/2297/1/012015

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 Nature Switzerland AG 2021. https://doi.org/10.1007/978-3-030-78720-2_1

Michelini M, Stefanel A (2021) A path to build basic quantum mechanics ideas in the context of light polarization and learning outcomes of secondary students. J Phys: Conf Ser 1929:012052

Michelini M, Stefanel A (2022) Quantum mechanics in teaching and learning physics: research-based educational paths for secondary school. In: McLoughlin E, Guisasola J (eds) Connecting research in physics education with teacher education, vol 3. ICPE Book, International Commission on Physics Education. https://doi.org/10.5281/zenodo.5792968

Michelini M, Santi L, Stefanel A, Meneghin G (2002) A resource environment to introduce quantum physics in secondary school. Proc Int MPTL-7. http://informando.infm.it/MPTL/

Michelini M, Lambourne R, Mathelisch L (eds) (2010) Multimedia in physics teaching and learning. Selected paper from the 14th MPTL Workshop (Udine 2009), SIF, Bologna and in Il Nuovo Cimento, 33 C, 3. NIFCAS 33(3):1–238. https://doi.org/10.13932/ncc/i2010-10620-3

Michelini M, Santi L, Stefanel A (2013) E-learning in teacher professional development in innovation and formative guidance on modern physics: the case of IDIFO master's programs. J e-Learn Knowl Soc 9(2)

Michelini M, Santi L, Stefanel A (2016) JQM per affrontare nella scuola secondaria i fondamenti di meccanica quantistica. In: Proceedings on-line del XXX Convegno Didamatica, Udine 19–21 Aprile 2016. http://didamatica2016.uniud.it/proceedings/dati/articoli/paper_96.pdf

Müller R, Greinert F (2021) Competence framework for quantum technologies: methodology and version history [Internet]. Directorate-general for communications networks C and T (European C, ed. LU: publications office of the European Union; [quoted 10. März 2022]. https://data.europa.eu/doi/10.2759/130432

Pallotta F (2022) Bringing the second quantum revolution into high school. PhD thesis, University of Insubria. https://doi.org/10.48550/arXiv.2206.15264

Pospiech G (1999) Teaching the EPR paradox at high school? Phys Educ 34(5):311

Pospiech G, Schöne M (2014) Quantum physics in teacher education. In: Frontiers of fundamental physics and physics education research, pp 407–416

Rogers MP, Abell S, Lannin J, Wang C-Y, Musikul K, Barker D, Dingman S (2007) Effective professional development in science and mathematics education: teachers' and facilitators' views. Int J Sci Math Educ 5(3):507–532. https://doi.org/10.1007/s10763-006-9053-8

See for example www.qplaylearn.com or https://www.scienceathome.org/games/quantum-moves-2/

Stadermann HKE, Goedhart MJ (2020) Secondary school students' views of nature of science in quantum physics. Int J Sci Educ 42:997

Sutrini C, Malgieri M, Macchiavello C (2022) Quantum technologies: a course for teacher professional development. J Phys: Conf Ser 2297:012018. https://doi.org/10.1088/17426596/2297/1/012018

Three Formats of Physics Education at Primary Level

M. Čepič, M. Giliberti, and D. Sokolowska

Abstract Formal, non-formal, and in-formal learning is very intertwined for younger learners in primary school. Therefore, it is worth exploring how to benefit from these three formats of learning in an organized and efficient way. The paper discusses what is understood by formal, non-formal, and informal learning and what their characteristics are. As the article focuses on primary school, we also discuss the meaning of this name, as "primary school" often has different meanings in different countries. Finally, we briefly discuss how pre-service and in-service teachers should be prepared so that they can benefit from what these three different types of learning offer and thus help to better support students.

1 Introduction

Historically, the teacher was the person who possessed the knowledge, and the transfer of this knowledge occurred during his/her teaching to students—the receivers of this knowledge. Results were sometimes better, sometimes worse, similar to what we observe even today. However, only a few decades ago, the receiver was given more importance and the teacher, and the methodology of teaching were seen as the means for establishing the student's reception of knowledge and further positioning of the received knowledge to the receiver's knowledge and experience network. The proper position of the new knowledge in the students' network of knowledge finally

---

M. Čepič (✉)
Faculty of Education, University of Ljubljana, Kardeljeva Pl. 16, 1000 Ljubljana, Slovenia
e-mail: mojca.cepic@pef.uni-lj.si

M. Giliberti
Physics Department, "Aldo Pontremoli" University of Milano, Via Celoria 16, 20133 Milano, Italy
e-mail: marco.giliberti@unimi.it

D. Sokolowska
Smoluchowski Institute of Physics, Jagiellonian University, Lojasiewicza 11, 30-348 Krakowç, Poland
e-mail: dagmara.sokolowska@uj.edu.pl

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2023

J. Borg Marks and P. Galea (eds.), *Physics Teacher Education*,
Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-44312-1_7

allows for comprehension and further use or application of new knowledge. This process is what we call "learning".

However, learning also covers information received in other circumstances, not just that from the teacher as a knowledgeable person. Indeed, in his famous book "Die Rükseite des Spiegels", Konrad Lorenz argues that all animal and human evolution can be seen as a process of acquiring knowledge in which the peculiarity of human culture is given by the manifestation of high levels of complexity and integration (Lorenz 1974).

Learning starts at birth, but it is difficult to distinguish early learning from the reflex reactions of a newborn child. Already a few weeks later, the child recognizes the mother's voice and circumstances that lead to actions pleasurable to the baby. Can the recognition of patterns from experience be called learning?

The early period of human life consists mostly of such experiential learning. How to walk, how to communicate, how to eat, how to dress, and many other everyday activities, are skills that children acquire in their early years, but there is no official education program for this. The child imitates the behaviour of older siblings and parents and suddenly, the child is able to communicate his/her ideas, pose questions and is prepared to acquire knowledge faster and more intensively.

Every child faces several channels that allow for learning. The most straightforward channel is communication with parents and pre-school teachers. These answer questions and they help children with different activities. The problem arises when parents may sometimes push learning to very young ages. This may often prevent a natural way of learning that depends on the child's development. For example, a child may be made to use a smartphone before the child is mentally and emotionally ready for it. On the other hand, taking another example, parents may find it easier to feed children themselves, rather than having to deal with mess children might create when doing this themselves. This then delays the skills required in this situation, which is also not advisable. One can thus say that situations like the ones described allow for skills to be forced to develop prematurely or too late.

As the child starts pre-school and primary school, learning becomes organized. Because it is systematic, children acquire new knowledge faster than by trial and error of non-systematic learning, under circumstances that are not organized. The organized learning is supported by teachers' actions, and results are also assessed or even evaluated. However, this is not the only mode of learning of a child that becomes a student. The child still plays with schoolmates, starts to read books of his/her choice, plays computer games, goes to a music school, practices his musical instrument, and may also go to sports training or to science centres for fun. It is evident that learning how to play a musical instrument, individually at a music school, differs from the learning process at a regular school where students are interacting with each other in a group. It can also be said that learning at a science centre may be more fun, since students can follow their interests, compared to learning a poem that a teacher chose to be learnt off by heart. But then, all these different situations of learning are important for the development of a child, and they contribute towards her/his network of knowledge acquisition.

In this contribution, we discuss learning in its different forms, that is, formal, informal, and non-formal. What are they? What are their roles? How are they intertwined and complement each other and how do they contribute to the knowledge of early science learners at their primary level of education? In addition, we here also consider the concept of the primary level of education, since it differs from one country to another. We discuss the main qualitative, semi-quantitative and quantitative properties that define this period. Finally, we discuss also how the three ways of learning should be included in teachers' education at the primary level.

2 Formal, Non-formal, and Informal Learning

Learning can be divided into three different types generally called formal, non-formal, and informal learning. There are several differences between them but in recent decades this division becomes less and less distinctive and in general, elements of different learning types are often included, integrated, and intertwined in the learning process of young students. Let us briefly discuss the characteristics of these three types of learning, their similarities, and differences (Ravanis 2017; Michelini 2010; Immè 2022).

2.1 Formal Learning

Formal learning is generally called learning within organized education programs. Usually, it starts with compulsory school and continues to high (grammar) school programs and later to education at undergraduate and graduate levels. The formal education system is regulated. Subjects with well-defined syllabi, curricula, and time allocation are a part of the regulation. Standards are set for the expected learning outcomes and quite often, also the methodology of teaching is suggested. Even more, many countries have established external evaluations of students' knowledge at different levels to ensure the quality of learning.

Formal learning in school is fostered by teachers whose employment is directly or indirectly financed by governments. For the implementation of teaching and learning, teachers can use various textbooks, workbooks, and, especially in science, also methodologically appropriate activities like experiments and lecture demonstrations. Teachers are professionals with a serious level of freedom for choosing methods and means to achieve the students' learning goals, however, in many countries, teachers can also choose some topics within a regular program that they like personally or that their students expressed an interest in.

In summary, formal learning is very structured, with known aims and goals, with a knowledge gain, which is also formally evaluated and finally certified. Formal learning is compulsory to a certain age and later is a precondition for professional occupations, for example, a medical doctor must complete well-defined programs. This is similar for teachers and many other professions.

2.2 Non-formal Learning

The main difference between non-formal and formal learning is that the former is unstructured and spontaneous, while the latter is more organized. Students undertaking non-formal learning can terminate the process at any time, without serious consequences for their compulsory education. The most prominent examples of non-formal education are music schools, organized training in sports and language courses. One can, however, easily recognize that such institutions organize non-formal learning with the help of their professionals and usually the learning is introduced in a very structured form, with known aims and goals and expected time allocations. From this perspective, non-formal learning becomes like formal learning with the main difference that it can be stopped without consequences if a student cannot fulfil goals or maybe loses motivation, as the learning is not compulsory. In addition, as the learning is non-formal, goals may be adapted to students' needs and the learning in general is then less structured than in formal settings.

2.3 Informal Learning

Finally, informal learning occurs constantly, in every situation. It is the basis of our communication and social skills, also learning habits and many other skills. Informal learning is usually not planned. It just happens. The new knowledge, skills, and attitudes are incorporated into the student web of competencies unconsciously. For young children, learning through play is very important, as also are children's discussions with parents and peers in pre-school and in other situations.

Informal learning is not usually structured, or when it is structured, the structure is usually imposed by a student him/herself or occurs due to circumstances. However, the knowledge and experience gained become connected to the knowledge network of the student in one way or another. Usually, the teachers often start their explanations by recalling this preliminary less structured knowledge.

2.4 Different Types of Learning in Physics Education

Learning physics, which is an experimental science, heavily relies on experience, especially in early science in primary education, when students meet reasoning patterns characteristic of physics for the first time. Within formal education, experience is provided intentionally and systematically with a clear goal to understand phenomena, how they can be observed and measured, how different variables influence outcomes and the like. In formal learning, experience purposely offered to students in physics topics is usually a result of either, demonstration experiments or experiments carried out by students in groups or individually. But a teacher can also combine different ways of experimenting. Observations or experiments can be carried out in non-formal institutions such as science centres or observatories, with telescopes for example, that provide equipment which is not available in school.

The teacher can therefore combine his/her own teaching within a formal setting, with part of the learning in a non-formal setting and combine both with the personal experience of students from everyday life, that is, the informally gained knowledge, skills, and attitudes. On the other hand, physics topics, especially in early science in primary school, are strongly related to everyday life. In addition, showing the relevance of new knowledge for the everyday experiences of students is another side of the coin that bridges formal learning with the non-formal and informal.

In physics, the boundaries between formal, non-formal, and informal education are more blurred than in the past. This is visualized in Fig. 1. Such a situation seems positive. It means that the deliberate use of experience from all three types of learning enhances students' knowledge and comprehension. For example, when playing with specific well-defined goals is incorporated into formal or non-formal learning, students often become more motivated. Therefore, combining all three is beneficial for students' learning, especially at the primary level, where students' learning is still less intentional and less planned.

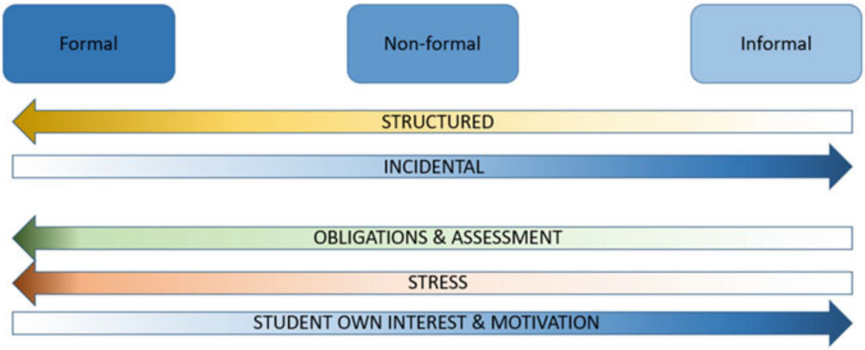


Fig. 1 Characteristics of three different types of learning. Arrows indicate the increasing importance of a specific characteristic, for example, formal learning is very structured but informal learning is very incidental. On the other hand, the same characteristics are present in any type of learning but their importance and share are different

3 Primary Education

Primary education is usually called the first few years of early formal education when students enter school. It is called also elementary school or elementary level of education and names are often used synonymously. Here, we discuss what is generally considered a primary school in Europe and how the process of education at that level is organized.

Although the name indicates the age of students and their level of knowledge, it is not the only meaning that is used. In some countries, primary school is also the name for the institution and students change the institution when they enter the lower secondary school, junior high school, or other types of schools that are available after the primary level. Sometimes, primary education is just part of the regular compulsory schooling, which includes also the lower secondary school, like in Slovenia, Italy or Poland, for example.

In some countries, like Slovenia and Italy, even public pre-schools have a curriculum and goals to facilitate children gaining information about everyday life. The preschool is not included under the primary education umbrella.

In general, students start with compulsory formal primary education when they are 5–7 years old (European Commission 2022). The age at entry is country-specific. Students are organized in classes of around 20 students, sometimes more, with the latter often in heavily populated areas or desired schools. Classes in less inhabited, remote areas with an ageing population are often much smaller. The learning in the first few years is mostly facilitated by a single teacher. Later, when learning topics become more specific and demanding, specialist teachers gradually join the teaching team. Most often, subject teachers teach foreign languages, gym, art or music because the primary teacher does not have enough experience or lacks the formal education, as a teacher of early learners of a foreign language, for example. Students' age at which subject teachers join the teaching team depends on many circumstances—on the country and specifics of the education system, on the availability of subject teachers, on the knowledge and experience of primary teachers, and other issues that may arise. Let us illustrate the variety of education structures with examples from authors' countries.

In Slovenia, the first 3 years in primary school are called also the first triad, students have only one teacher, who finished the bachelor's and the master's study programs for primary teachers. In the second triad, in grades 4–6, subject teachers gradually join the teaching team, up to the sixth grade. Therefore, the transition from elementary level to lower secondary level occurs between the 5th and the 6th grades. Finally, the last 3 years of compulsory school are taught by subject teachers who also have to finish the teacher programs to the level of master from their speciality. Most often teachers in compulsory schools teach two different subjects. Topics related to physics or science, in general, are taught by a primary teacher at the elementary level and by a physics teacher who finished the study program for physics teachers at the lower secondary level.

In Italy, primary school education includes 5 years of study starting from the age of 6. The teachers are graduates of primary education sciences, a 5-year degree course (300 credits) that provides a title equivalent to a master's degree. There are basically two teachers per class and they can divide the disciplines taught according to their skills. However, in general, one of the two teaches linguistic-humanistic subjects (Italian, history, art, geography, English), while the other teaches mathematics, science, music, and sports (except in the last year where there is a specialist). In addition, there is a religion teacher for those who take these lessons. However, to teach English, a specific specialization is needed. If the two class teachers do not have it, another teacher from the school conducts these lessons.

According to the latest education reform in Poland, primary school starts at the age of seven. However, at the age of 6, children go through a compulsory preschool program, organized either in kindergarten (full-time) or at primary school (several hours a day). During the first 3 years of primary school, one teacher provides all classes, except for the English language and religion lessons, and thus the program combines different activities in a holistic way, without specific division into separate subject lessons. These teachers need to complete a minimum of the bachelor's degree study. Starting from the 4t grade, the curriculum is divided into separate subjects taught by different subject teachers, who need to complete the master's degree in their subject, combined with a pedagogical program. From grade 4 to 7, more subjects are included one by one in the curriculum. Natural science subjects are a small proportion of all subjects, similar to other EU countries (European Commission and Eurydice 2021). Many mathematics and science subjects' teachers take additional training to be entitled to teach other allied subjects, due to a variety of reasons (the shortage of teachers, teacher salary level, etc.). Primary school is identical to obligatory school and lasts 8 years, however, the last 2 years are in fact at the level of lower secondary (ISCED 2).

4 Teachers' Education for Primary Level

Up till a few decades ago, 2 years of education after upper secondary school was the minimal requirement level of education for primary teachers. However, the required education for primary teachers has now drastically changed across Europe. On average, across Europe, 4 years of a primary teacher program is required (European Commission/EACEA/Eurydice 2013) and the programs cover the content knowledge, the teaching methodology of specific contents for the primary level of education and general subjects on psychology, methodology of teaching, social aspects of education and similar topics. In some countries, primary science deals mostly with biological concepts, however, in other countries, it covers the life and physical science, and in some cases, also some technological content. When finishing the program, primary teachers have a general overview of all sciences and national languages, usually also the introductory foreign language, math, arts, and sports. One can easily notice that deep understanding in such a large plethora of subjects cannot be reached and teachers usually possess a higher level of knowledge in subjects they are more motivated for. In this respect, one must mention that prospective primary school teachers are very often not enthusiastic in any field of science and it is a difficult task for lecturers, but not an impossible one, to motivate students for science and to persuade them that science allows students to develop skills very important for life, such as the skills of observation, planning, and drawing conclusions from facts and not from hearsay.

As science teaching at the primary level could benefit from formal, non-formal, and informal aspects of education, the most positive attitudes towards learning science can probably be fostered in children through non-formal activities. In fact, education in scientific thinking should also present formal educational experiences that are in continuity with non-formal and informal ones. Scientific knowledge, in fact, arises from experiences that can be proposed from an early age and continue in a conceptual construction that, in primary school, is essentially based on experience. At this age level, however, it cannot have rigidly disciplinary characteristics yet. The basic experiences are generally transversal; they are experiences of making and experimenting which, in current practice, often risk—already in primary school—of being too tied to the disciplines and for this reason, categorized. The subdivision into disciplines should be somewhat overshadowed, at least in this first training segment. But for this to be possible (Immè 2022), it is, therefore, necessary that their components are included in teachers' programs in the pre-service and the in-service contexts. Teachers must learn how to plan coherent non-formal/formal activities starting from informal environments in a school, able to connect different aspects of education providing suitable bridges, as they should not be too closely linked to textbooks nor to formulas and take the opportunities that come out of society: exhibits, theatre, cartoons, virtual labs, and so on.

However, as teachers tend to teach as they were taught, non-formal and in-formal components must be a part of regular pre-service programs. One example from Slovenia seems quite efficient, as evidenced by discussions with former students, in-service teachers today. The program for primary teachers allows for a sort of specialization of a teacher. In new programs for primary teachers, such specialization can be achieved by proper choice of elective professional subjects. Some students choose English for early learners, but even science-oriented subjects are available. To quote three of them, one focuses on experimental work of early science, the second focuses on games as a tool for learning science, and the third focuses on fieldwork in science, where students visit science centres, natural parks, and similar venues. All three subjects, especially stress learning aspects and methodological approaches during the activities and visits, which enable students to experience and receive the preparation that can be later directly applied in school.

It is a quite common opinion, supported by many studies (Osborne et al. 2003; Hofstein et al. 2011) that mathematics and science subjects are not very popular among students, mostly due to their very theoretical delivery at school. To support overcoming a threshold of this reluctance, non-formal labs and workshops for students, in-service teachers, and for both, play a key role. Non-profit organizations (https://www.swietlik.edu.pl) and university labs (Affeldt et al. 2017; https://www.matematita.it/) open up to the public and provide enjoyable science and mathematics activities. Such initiatives not only improve students' interest and motivation by providing a different perspective on disliked subjects in the out-of-school environment but also give a boost to teachers, who are educated in a traditional, theoretical format and often express their own reservations towards learning by experimenting (Roberts et al. 2008; Anastopoulou et al. 2012; Tan and Caleon 2016), not realizing the potential and feasibility of simple experimental inquiries done by students (Sokołowska 2018).

We have already seen that, especially in primary school, teaching/learning strategies cannot be primarily based on concepts. Concepts, in fact, are refined mental constructions that arise at the end of a long and tiring elaboration and certainly not at the beginning of the teaching/learning path. It is precisely in the context of formalized disciplines that we find the necessary structures to understand disciplinary concepts and their connections, however, it is not by strictly following the codified disciplinary structure that effective learning is achieved (Cavallini and Giliberti 2008).

We do not acquire knowledge only through rational elaboration; sounds, colours, movements, etc.—they are all part of the learner's world and allow the young student to construct representations of the world around her/him. Therefore, for example, while teaching we are dealing with light, we should avoid selecting only focusing on optics, but also pay attention to colours and the vision and the sensations they generate, the emotions they produce and the way we are able to express them. With such attention, the learning context becomes broad and multidisciplinary in a natural way. When the topics discussed are meaningful to people (because they are perceived as useful, interesting, or fascinating), interest, attention and the desire to understand are more easily obtained. The use of stories is a way to draw attention to significant issues. Indeed, a very effective way to engage students in science is to use storytelling; in fact, on the one hand, it attracts the attention of young students and keeps them completely focused on what is told (Abrahamson 1998) and on the other hand, the story constitutes a common thread along which to propose a scientific activity and develop imaginative thinking in a coherent picture (Bernardini et al. 1995).

Another tool very close to narration is scientific theatre (Giliberti 2021). It can be extremely useful for promoting interactions between people, society, and school (Carpineti et al. 2006). In general, it manages to develop scientific imagination, to promote learning thanks to emotional involvement and to enhance both personal needs and an approach to physics through affectivity. Furthermore, the theatre also helps reduce cultural and gender gaps by promoting a more humane and profound scientific culture (Ødegaard 2003; Fazio et al. 2021; Giliberti 2014).

Drama features a conflict that needs to be resolved; this fact generates attention and keeps the audience focused and responsive. If the conflict or the game leads to questions about the phenomenological (or even conceptual) aspects of physics, the emotional involvement of the spectator towards physics itself can arise, generating interest in an active way. Both storytelling and scientific theatre are tools that can be used in a formal or informal context.

5 Conclusions

The paper discusses three main formats of education of physics in primary education (formal, non-formal, and informal), how they support each other and how they can be used for increasing students' motivation for science. At early ages, the effectiveness of teaching and learning depends very much, probably even more than in subsequent stages, on bringing together (1) students' experiences and positive attitudes from informal education done mostly at home, (2) students' interest and motivation that become stronger during episodes of the non-formal education, and (3) the formal education structure, tailored to boost the development of competences. We believe that each format separately contributes less effectively to physics education at the primary level than when they intertwine. Thus, pre-service-teacher programmes and in-service teacher training have to include direct (prospective) teachers' experience with non-formal and in-formal learning in order to make teachers aware of these aspects and provide them with tools and strategies to combine all three formats of physics education in their teaching practice.

References

Abrahamson CE (1998) Storytelling as a pedagogical tool in higher education. Acad J Artic Educ 118(3):440–445

Affeldt F, Tolppanen S, Aksela M, Eilks I (2017) The potential of the non-formal educational sector for supporting chemistry learning and sustainability education for all students–a joint perspective from two cases in Finland and Germany. Chem Educ Res Pract 18(1):13–25

Anastopoulou S, Sharples M, Ainsworth S, Crook C, O'Malley C, Wright M (2012) Creating personal meaning through technology-supported science inquiry learning across formal and informal settings. Int J Sci Educ 34:251–273. https://doi.org/10.1080/09500693.2011.569958

Bernardini C, Tarsitani C, Vicentini M (1995) Thinking physics for teaching. Plenum Press, New York, NY, USA. ISBN 0-360-45192-1

Cavallini G, Giliberti M (2008) La lezione della fisica quantistica. Epistemologia 31:219–239

Carpineti M, Cavallini G, Giliberti M, Ludwig N, Mazza C, Perini L (2006) Let's throw light on matter: a physics show for primary school. Il Nuovo Cim Della Soc Ital Di Fis B Gen Phys Relativ Astron Math Phys Methods 121:901–911. https://doi.org/10.1393/ncb/i2007-10022-7

European Commission, European Education and Culture Executive Agency, *Compulsory education in Europe: 2022/2023*, Publications Office of the European Union, 2022, https://doi.org/10.2797/235076. Accessed 30 Nov 2022

European Commission EACEA, Eurydice (2021) Recommended annual instruction time in full-time compulsory education in Europe—2020/21. Eurydice—Facts and Figures. Publications Office of the European Union, Luxembourg https://eurydice.eacea.ec.europa.eu/publications/recommended-annual-instruction-time-full-time-compulsory-education-europe-202021. Accessed 30 Nov 2022

European Commission/EACEA/Eurydice (2013) Key data on teachers and school leaders in Europe. 2013 Edition. Eurydice Report (Luxembourg: Publications Office of the European Union) https://op.europa.eu/en/publication-detail/-/publication/17ad39ad-dcad-4155-8650-5c63922f8894. Accessec 30 Nov 2022

Fazio C, Carpineti M, Faletič S, Giliberti M, Jones G, Mcloughlin E, Planinšič G, Battaglia OR (2021) Strategies for active learning to improve student learning and attitudes towards physics.

In: Jarosievitz B, Sükösd C (eds) Teaching-learning contemporary physics: from research to practice. Springer, Berlin/Heidelberg, Germany, pp 213–233. ISBN 978-3-030-78719-6

Giliberti M (2014) Fisica a teatro (Lo scrigno di Prometeo). Ariccia, Italy, Aracne. ISBN, 8854877069, EAN: 9788854877061

Giliberti M (2021) Stories and theatre for teaching physics at primary school. Educ Sci 11:1–14

Hofstein A, Eilks I, Bybee R (2011)Societal issues and their importance for contemporary science education—a pedagogical justification and the state-of-the-art in Israel, Germany and the USA. Int J Sci Math Educ 9:1459–1483

Immè J (2022) Le questioni affrontate durante il convegno “Quale didattica della fisica per formare gli insegnanti di scuola primaria?” Which kind of physics education for prospective primary teachers? GIORNALE DI FISICA LXIII PLS-Fisica-FIP. https://doi.org/10.1393/gdf/i2022-10484-2

Lorenz K (1974) L’altra faccia dello specchio. Adelphi, Milano

Michelini M (2010) Building bridges between common sense ideas and a physics description of phenomena to develop formal thinking. In: New trends in science and technology education. In: Menabue L, Santoro G (eds) Selected papers, vol 1. CLUEB, Bologna, pp 257–274. ISBN 978-88-491-3392-9

Ødegaard M (2003) Dramatic science. A critical review of drama in science education. Stud Sci Educ 39:75–101

Osborne J, Simon S, Collins S (2003) Attitudes towards science: a review of the literature and its implications. Int J Sci Educ 25(9):1049–1079

Ravanis K (2017) Early childhood science education: state of the art and perspectives. J Baltic Sci Educ 16:284

Roberts E, Shaw J, Weaver D, Lang M (2008) Writing-to-learn in the inquiry-science class-320 room: effective strategies from middle school science and writing teachers. Clear House 81(3):105–108. https://doi.org/10.3200/TCHS.81.3.105-108

Sokołowska D (2018) Effectiveness of learning through guided inquiry. In: Sokołowska D, Michelini M (eds) The role of laboratory work in improving physics teaching and learning. Springer Nature, Switzerland AG, pp 243–255

Tan YSM, Caleon IS (2016) Dealing with the ambiguities of science inquiry. Phys Teach 54(3):168–171. https://doi.org/10.1119/1.4942141

www.swietlik.edu.pl

https://www.matematita.it/

Pre-service Physics Teacher Education at Primary and Secondary Levels

Claudio Fazio and Zuzana Ješková

Abstract Pre-service teacher education is important in preparing future teachers who can effectively support student learning. In order to do this, pre-service teachers must acquire, among other things, teaching-oriented content knowledge and a positive stance with regard to teaching and motivation towards teaching. Many more issues are linked to pre-service teacher education. In this paper, we discuss some issues raised and answers proposed about this subject during the GIREP Malta 2021 Webinar Work Group 5 discussions regarding pre-service physics teacher education.

1 Introduction

A proper pre-service education of science teachers, supplemented by a continuous professional development programme, is today widely considered as a crucial factor for effective teaching that improves the quality of student learning (European Commission: Strengthening teaching in Europe 2015).

This can be said in relation to both conceptual understanding and teaching methodology. Research (Ndlovu et al. 2017; Wang and Buck 2016; Mellado 1998; Zuckerman 1999; Mäntylä and Nousiainen 2014; Tiberghien et al. 1998) shows that in many countries pre-service science teachers bring to teacher education coursework a conceptual understanding quite different from the one that they are supposed to develop in their future pupils in order to make them able to effectively describe and explain the natural phenomena. Moreover, there is a wide consensus in admitting that pre-service teachers, instructed by means of traditional university educative methodologies and approaches, often focus on a one-way transmission (i.e., from the instructor to the learner) of abstract and decontextualized principles and laws.

C. Fazio (✉)
Università degli Studi di Palermo, Palermo, Italy
e-mail: claudio.fazio@unipa.it

Z. Ješková
Faculty of Science, Pavol Jozef Šafárik University in Košice, Šrobárova 2, Košice, Slovakia
e-mail: zuzana.jeskova@upjs.sk

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2023

J. Borg Marks and P. Galea (eds.), *Physics Teacher Education*,
Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-44312-1_8

As a consequence, they may bring, even unknowingly, the same approaches in their teaching, without any attempt on their part to adapt it to the needs of their future students. Research has shown that an abstract and decontextualized education, which often ignores the interdependence of situation and cognition, may lead the students to see knowledge of principles and laws as the final product of education, rather than a tool to be used dynamically to solve problems (Herrington and Oliver 2000).

A possible way to address this issue is to devote part of pre-service teacher education programmes to an introduction to active learning methodologies. These methodologies have received considerable attention over the last several years and are commonly presented in the scientific literature as a solution to the reported lack of efficacy of more traditional educative approaches (Cummings 2013). Active learning methods and strategies are credited as ways to improve student conceptual understanding in many fields, including physics (e.g., Cummings 2013; Georgiou and Sharma 2015; Sharma et al. 2010; Hake 1998; Redish and Smith 2008). For these reasons, active learning has gained strong support from teachers and lecturers within faculties looking for effective alternatives to traditional teaching methods.

Thus, the starting point for an "effective" pre-service teacher training model should be the consideration that it cannot be limited to a training programme dealing with simple ways of transmitting simplified disciplinary knowledge, together with some additional information on general pedagogical/didactical methods. Rather, an effective pre-service teacher training model should provide future teachers with tools and methodologies that can allow them to "reconstruct" (e.g., Duit et al. 2012) the disciplinary contents and the general pedagogical tools and methodologies, adapting them to the needs of the students and to the learning difficulties known from research. In fact, it is well known from research literature that to develop a suitable initial professional knowledge base (one that takes into account what students already know (including their actual difficulties, etc.), teachers do not only need to know general educational strategies. They also need to directly experiment with how particular instructional strategies can be implemented in their specific content domain (Ball et al. 2008), activating profound reflection on the conditions of effectiveness of such strategies in daily teaching practice (Schön 1988; Sellars 2017).

Furthermore, it should be necessary to take into account the problems of understanding, motivation and beliefs of students (and of teachers, see Bandura 1986; Berry et al. 2015) about their role in learning. Finally, attention should be paid to make future teachers aware of the main results of research in the cognitive sciences and in disciplinary teaching, which can provide significant contributions towards the contextualization of teaching problems and suggestions for approaches to their resolution.

In 2015, Gess-Newsome (2015) proposed a consensus model of teacher professional knowledge and skill in science education research to describe in detail the teachers' professional knowledge base—a construct well known in the literature as "Pedagogical Content Knowledge" (PCK). PCK was first proposed by Shulman (1986, 1987), and several scholars have contributed to our understanding of it (e.g., Alonzo et al. 2012; Wenning et al. 2011; Abell 2008; Loughran et al. 2004). The key idea is that the effectiveness of teachers' instructional strategies to teach a certain topic depends on the understanding of how students learn that topic and on the awareness that learning may vary according to several factors, such as the specific educational contexts and students' ideas. The more teaching strategies teachers have at their disposal within a certain subject domain, the better they understand their students' learning processes in the same domain, the more effectively they can plan, teach and reflect effectively in the classroom context to support student learning in that domain.

With an intensive development of digital technologies and their role to enhance teaching and learning, this model was further elaborated upon and extended to TPCK or TPACK framework, which includes technological, pedagogical and content knowledge combined in various ways. According to TPACK framework, specific technological tools are best used to instruct and guide students toward a better, more robust understanding of the subject matter (Mishra and Koehler 2006). As a result, the practices in pre-service teacher education should involve strategies that better prepare teachers to effectively integrate technology into their teaching (Schmidt et al. 2009).

Another framework that elaborated on the need to develop educators' competencies to master digital technologies is the European Framework for the Digital Competence of Educators (DigCompEdu) (Punie and Redecker 2017). This document is an excellent starting point for fostering educators' digital competence, by offering a common frame of reference, with a common language and logic (Punie and Redecker 2017). This framework emphasizes the development of digital competencies educators need to foster efficient, inclusive and innovative teaching and learning strategies.

2 Work Group 5 Discussions

All these considerations have been taken into account in the Work Group 5 (WG5) discussions, during the 2020 GIREP Webinar organized by the University of Malta. Conclusions have been reached in order to answer some questions that have been found to be of general interest in the field of pre-service physics teacher education programmes, thus offering possible strategies for enhancing these programmes.

The questions discussed during the 2020 Webinar can be summarized as follows:

1. What is an adequate format for a pre-service physics teacher education programme?
2. What sort of content structure should be the basis for a twenty-first century pre-service physics teacher programme?
3. What teaching and learning strategies can help to improve pre-service physics teacher education?
4. How should teacher education use and promote digital competence to enhance both face-to-face and online teaching?

More details on the questions and a discussion on the answers arising from the Work Group 5 discussions in 2020 may be found in Couso et al. (2297).

In 2021, another edition of the GIREP Webinar was organized by the University of Malta. The 34 participants to WG5 again worked on themes regarding pre-service teacher education, trying to focus on some relevant issues already highlighted during the 2020 discussions and not completely addressed at that time. These issues can be summarized as follows:

1. Developing competencies of pre-service teachers to effectively enhance physics teaching and learning in active learning environments;
2. Challenges and potentialities of physics teacher education to develop teachers' competencies for online teaching;
3. Preparing non-physicists to be physics teachers: is that remotely possible?

In the following sections, we will report the main points that emerged from the 2021 discussions, and the issues raised by the contributors to Work Group 5.

2.1 Developing Competencies of Pre-Service Teachers that Effectively Enhance Physics Teaching and Learning in Active Learning Environments

The routes adopted worldwide to enhance physics teaching and learning are different with reference to primary and secondary education. The participants of WG5 agreed that, in general, pre-service primary teachers are mainly presented, with a lot of transversal (i.e., pedagogical, anthropological and psychological) themes during their education programmes. Content knowledge is presented and discussed during these programmes, but it is often given less attention and importance than the transversal themes. This is probably due to the belief that the contents to be presented at primary level are sufficiently simple to be considered less important than the teaching methodologies. Conversely, pre-service teacher education programmes targeting secondary education usually put more emphasis on content and sometimes less attention is paid to pedagogical approaches and psychological issues.

However, for both primary and secondary pre-service teacher education levels, the relevance of making the pre-service teachers aware of the significance of active learning emerged strongly from the discussion. All participants also agreed that the best way to make future teachers aware of active learning and its effectiveness would be to introduce this methodology during the years of university study. In fact, it has been reported, that very often, teachers transfer methods and contents learned during their studies into their classrooms, sometimes simplifying the approaches and adopting, in an uncontextualized way, the teaching models used by textbooks (Sprinthall et al. 1996).

An active involvement of university students in the learning processes should be fostered also during content-oriented courses, these being theoretical or laboratory-based ones. In particular, it is worth noting that both the laboratory activities and the in-class work assignments should avoid a "cook-book" structure and should be organized in order to give students the freedom to follow their ideas and also make mistakes, to understand that the path followed was possibly not the best one.

Interestingly enough, some WG5 participants highlighted that a number of teachers sometimes express doubts about what active learning really is and how it can be considered different from traditional education. Particularly, they claim that their teaching methods can already be considered “active”, in terms of setting homework assignments and in doing laboratory work. However, all agreed that involving students in active learning is more than simply performing tasks such as in-class work or homework exercises. Research has shown that effective active learning is always based on a broad range of pedagogical processes that emphasize the relevance of student ownership of the discipline and activation of high-level and critical thinking skills (e.g., https://tinyurl.com/yh52fyw9). In particular, real active learning methodologies harness the benefits of curiosity-driven methods and research-based/problem-based/team-based/context-related learning, thus stimulating learning that is meaningful and significant to the students.

2.2 Challenges and Potentialities of Physics Teacher Education to Develop Teachers’ Competencies for Online Teaching

The development of teachers’ competencies for online teachers suddenly became a highly relevant and debated issue in 2020, due to the COVID-19 pandemic. The closure of schools throughout the world pushed teachers at both school and university levels to quickly adapt to the challenging situation of overnight transforming their teaching plans to fit the needs of online distance learning. This required teachers to rapidly develop their level of digital competence, not only with respect to the simple use of digital platforms and Learning Management Systems (Zoom, Teams, Meet, Moodle, etc.) for direct online teaching, but also with regard to a more advanced use of these systems for building and administering surveys, questionnaires, educational paths, etc. During the WG5 discussions, it was made clear that technology-enhanced learning environments can be very useful to support active learning by enhancing student collaboration and knowledge building, to allow visualization of a problem through specific tools (e.g., Guillén-Gámez et al. 2022), to make students aware of their learning progress (Marcelo and Yot-Domínguez 2019) even in a distance learning situation. However, all the participants agreed that the teacher cannot be left alone to face the challenges posed by the developments of the competencies needed for proper online teaching: an effective pre-service education programme should devote a reasonable amount of time to introduce future teachers to the use of digital technologies for teaching and help them develop competences in this field. Pre-service teachers must be supported in developing integrated knowledge, skills and attitudes in the digital area and in this sense, the pre-service teacher educational programmes should be aware of frameworks like the Technological Pedagogical

Content Knowledge (TPACK) one (Mishra and Koehler 2006; Schmidt et al. 2009; Koehler et al. 2013). This framework highlights the importance of integrating digital technology knowledge with pedagogical content knowledge. The more the three different types of knowledge identified by TPACK (content knowledge, pedagogical knowledge and technological knowledge) overlap and interact, and the more aware teachers become of the complex interactions between them, the more effective teaching becomes when using digital tools. This can result in having technology-supported pedagogical methods to become profitably used to teach content (Koehler et al. 2013) and support student development of skills, even in difficult and challenging situations like distance learning. As also stressed by the European Framework for the Digital Competence of Educators (DigCompEdu) (Punie and Redecker 2017), digital technologies can enhance and improve teaching and learning strategies in many different ways. Nevertheless, the fundamental competence of the teacher refers to designing, planning and implementing the use of digital technologies in the different stages of the learning process. In other words, the success of digital technologies depends strongly on the pedagogical methods and students can benefit from their use only if the appropriate pedagogical methods and strategies are selected and implemented at the right time. This is especially true in implementation of active learning strategies such as inquiry-based strategies, where digital technologies, if implemented properly, can play an important role in students' independent investigations. Another aspect discussed during the WG5 activities regarded the possible ways to plan and conduct laboratory activities (experiments and simulations) in the pre-service physics teacher education phases focusing on online teaching. Many WG5 participants highlighted their experience with remote-controlled experiments that some universities make available on the internet and were widely used during the COVID-19 pandemic. The significance for learning of real-time measurements performed by the teacher and/or the students and synchronized with video recording of the experiment phases and made available to all the students by means of the internet was also discussed, as well as the use of simulations, augmented reality and videogame tools.

2.3 *Preparing Non-Physicists to Be Physics Teachers: Is that Remotely Possible?*

Teachers can strongly influence the development in students of a proper understanding of science as a human endeavour and provide the science and technology workforce of the future. Every student should have the support of a highly qualified teacher and this obviously holds true also for science teachers. Poor teacher preparation denies students access to a quality education in all disciplinary areas. In science, students who have not had a good high-school science teacher often approach introductory college science courses unprepared from both the methodological and the basic knowledge points of view.

The situation of teachers in primary schools is complicated. Primary school teachers are traditionally mainly trained to deal with pedagogical and cognitive psychology issues and often do not possess good science content knowledge. However, in recent years and in many countries, attention has been focused on the improvement of pre-service primary teacher education, also with respect to the science content. Many programmes for pre-service primary teacher education all around the world include the didactics of several subjects, including physics. However, the problem of a less than perfect preparation to teach science, and physics in particular, is also present at the secondary school level. In fact, in many countries, few physics teachers have a degree in physics, and even fewer have a degree in physics education.

Due to the lack of properly trained physics teachers in many countries, the Universities open study programmes for engineers or teachers of science topics who are not physicists, to complete their education and become qualified physics teachers. These programmes are usually designed with a set fraction of the length of the standard pre-service teacher study programme. The experiences with these programmes seem constrained and contradictory. One of the most limiting factors is the large gap between the study programme requirements and the actual skills and content understanding of the applicants. As a result, the study programme is often simplified and tailor-made to the secondary school curriculum, as opposed to a standard pre-service teacher study programme for physics specialists. This is one of the possible ways for some countries to address the huge decline in the number of active in-service physics teachers. The aforementioned situations are common to many countries, among the ones represented by the participants to WG5 and there are many open questions and challenges that still need to be answered and solved for all stakeholders in this field.

3 Conclusions

All the participants taking part in the WG5 discussion agreed that making pre-service physics teachers, at both primary and secondary levels, aware of the significance of active learning can enhance students' understanding of physics and of its methods. All also agreed that the best way to make future teachers aware of the effectiveness of active learning methodologies would be to introduce them to this methodology during the years of their university studies.

A lot of work has been done in some countries, also in the framework of national and international projects, to introduce in-service physics teachers to active learning methodologies and to trial them in real classrooms. The same could be done also in pre-service teacher education programmes, possibly with the help of experienced teachers who may have been previously exposed to professional development focused on active learning. It should be useful to create communities of learners (Cathcart et al. 1996; Shulman 1997), consisting of experienced school teachers and university researchers, as well as pre-service teachers who could discuss the issues related to effectively applying active learning methodologies in class and activate social exchange of experiences, skills and competences. Specifically, the importance of learning by inquiry and through investigation-based activities should be discussed having the experienced teachers presenting their experience to the pre-service ones. In this way, pre-service teachers could directly understand that curiosity-driven and research-based methods can stimulate forms of learning that are meaningful to the students and thus result in being more effective, from a pedagogical point of view.

Moreover, among the WG5 participants, there has been broad consensus that a proper use of technology-assisted learning environments can be beneficial for enhancing pre-service physics teacher education. All the participants agreed that future teachers should be well trained to properly use digital technologies for teaching, developing competencies in this field. Pre-service teachers must be supported in developing and using integrated knowledge and professional skills in the digital area, especially after these proved so important during the recent COVID-19 pandemic.

References

Abell SK (2008) Twenty years later: does pedagogical content knowledge remain a useful idea? Int J Sci Educ 30(10):1405–1416. https://doi.org/10.1080/09500690802187041

Alonzo AC, Kobarg M, Seidel T (2012) Pedagogical content knowledge as reflected in teacher-student interactions: analysis of two video cases. J Res Sci Teach 49(10):1211–1239. https://doi.org/10.1002/tea.21055

Ball DL, Thames MH, Phelps G (2008) Content knowledge for teaching: what makes it special? J Teach Educ 59:389–407

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

Berry A, Friedrichsen PJ, Loughran J (2015) Teaching and learning in science series. Re-examining pedagogical content knowledge in science education. Routledge, New York, p 28

Cathcart R, Samovar L, Henman L (1996) Small group communication: theory and practice, 7th ed. Brown and Benchmark, Madison

Couso D, Fazio C, Ješkova Z (2022) Work group 5 position paper: strategies for pre-service physics teacher education. J Phys: Conf Ser 2297 012024

Cummings K (2013) A community-based report of the developmental history of PER. In: Paper presented at the American Association of Physics Teachers, Portland, Oregon

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 (ed) Science education research and practice in Europe. Cultural perspectives in science education, vol 5. Sense Publishers, Rotterdam, pp 13–37

European Commission: Strengthening Teaching in Europe (2015) New evidence from teachers compiled by Eurydice and CRELL. http://ec.europa.eu/education/library/policy/teaching-profession-practices_en.pdf

Georgiou H, Sharma MD (2015) Does using active learning in thermodynamics lectures improve students' conceptual understanding and learning experiences? Eur J Phys 36:015020

Gess-Newsome J (2015) A model of teacher professional knowledge and skill including PCK. In: Berry A, Friedrichsen PJ, Loughran J (eds) Re-examining pedagogical content knowledge in science education. Routledge, New York, p 28

Guillén-Gámez FD, Cabero-Almenara J, Llorente-Cejudo C, Palacios-Rodríguez A (2022) Differential analysis of the years of experience of higher education teachers, their digital competence

and use of digital resources: comparative research methods. Tech Know Learn 27:1193–1213. https://doi.org/10.1007/s10758-021-09531-4
Hake RR (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
Herrington J, Oliver R (2000) An instructional design framework for authentic learning environments. Educ Techno Res Dev 48(3):23–48
https://tinyurl.com/yh52fyw9
Koehler MJ, Mishra P, Cain W (2013) What is technological pedagogical content knowledge (TPACK). J Educ 193(3):13–19. https://doi.org/10.1177/002205741319300303
Loughran J, Mulhall P, Berry A (2004) In search of pedagogical content knowledge in science: developing ways of articulating and documenting professional practice. J Res Sci Teach 41:370–391
Mäntylä T, Nousiainen M (2014) Consolidating pre-service physics teachers' subject matter knowledge using didactical reconstructions. Sci Educ 23:1583–1604. https://doi.org/10.1007/s11191-013-9657-7
Marcelo C, Yot-Domínguez C (2019) From chalk to keyboard in higher education classrooms: changes and coherence when integrating technological knowledge into pedagogical content knowledge. J Further Higher Educ 43(7):975–988. https://doi.org/10.1080/0309877x.2018.1429584
Mellado V (1998) The classroom practice of preservice teachers and their conceptions of teaching and learning science. Sci Educ 82:197–214
Mishra P, Koehler MJ (2006) Technological pedagogical content knowledge: a framework for a framework for teacher knowledge. Teach Coll Rec 108(6):1017–1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x
Ndlovu Z, Amin N, Samuel MA (2017) Examining pre-service teachers' subject matter knowledge of school mathematics concepts. J Educ 70:46–72
Punie Y, Redecker C (2017) European framework for the digital competence of educators: DigCompEdu. EUR 28775 EN. Publications office of the European Union, Luxembourg. ISBN 978-92-79-73718-3 (print), 978-92-79-73494-6 (pdf). https://doi.org/10.2760/178382 (print), https://doi.org/10.2760/159770 (online), JRC107466
Redish EF, Smith KA (2008) Looking beyond content: skill development for engineers. J Eng Educ 97(3):295–307
Schmidt DA, Baran E, Thompson AD, Mishra P, Koehler MJ, Shin TS (2009) Technological Pedagogical Content Knowledge (TPACK): the development and validation of an assessment instrument for preservice teachers. JRTE 42(2):123–149
Schön D (1988) Coaching reflective thinking. In: Grimmet PP, EricKson GL (ed) Reflection in teacher education. Teacher College Press, New York, pp 19–29
Sellars M (2017) Reflective practice for teachers. SAGE, London
Sharma MD, Johnston ID, Johnston HM, Varvell KE, Robertson G, Hopkins AM, Thornton R (2010) Use of interactive lecture demonstrations: a ten-year study. Phys Rev Spec Top Phys Educ Res 6:020119
Shulman LS (1986) Those who understand: knowledge growth in teaching. Educ Res 15(2):4
Shulman LS (1987) Knowledge and teaching. Foundations of the new reform. Harvard Educ Rev 57(1)
Shulman LS (1997) Communities of learners and communities of teachers. The Mandel Leadership Institute, Jerusalem
Sprinthall NA, Reiman AJ, Thies-Sprinthall L (1996) Teacher professional development. In: Sikula J (ed) Second handbook of research on teacher education. Macmillan, New York, pp 667–703
Tiberghien A, Jossem EL, Barojas J (1998) Connecting research in physics education with teacher education. Int Comm Phys Educ Book
Wang J, Buck GA (2016) Understanding a high school physics teacher's pedagogical content knowledge of argumentation. J Sci Teach Educ 27(5):577–604

Wenning C, Wester K, Donaldson N, Henning S, Holbrook T, Jabot M, Truedson J (2011) Professional knowledge standards for physics teacher educators: recommendations from the CeMaST commission on NIPTE. J Phys Teach Educ Online 6(1):1–7

Zuckerman JT (1999) Student science teachers constructing practical knowledge from inservice science supervisors' stories. J Sci Teach Educ 10(3):235–245

Strategies for Enhancing Physics Teacher Education at Secondary and University Level

Eilish McLoughlin, Gerald Feldman, and Wim Peeters

Abstract This paper presents an overview of strategies used for in-service physics teacher professional learning which were presented at the Groupe International de Recherche sur l'Enseignement de la Physique (GIREP) 2020 and 2021 Seminars hosted by the University of Malta. The findings presented in this paper have been collated from contributions to Working Group 6 during the seminars in 2020 and 2021 in the form of oral presentations, survey responses, and contributions to focus group discussions. This position paper provides unique insights into how physics teacher education is organized at secondary and university level across different countries. We discuss what strategies are being used to support physics teachers' learning and how teachers' needs are identified and addressed in the design and implementation of professional learning programmes. This paper presents details of how evidence of the impact of different strategies for physics teacher education has been collected and evaluated in different countries/programmes. We conclude that reviewing strategies and measuring the effectiveness of strategies used for physics teacher education is essential to ensuring the influence and sustainability of teacher professional learning.

1 Introduction

Education systems must adapt to the rapidly changing landscape of the global economy and society in order to prepare learners to live and thrive in a complex and connected society. Thus, now, more than ever, providing support for physics

---

E. McLoughlin (✉)
School of Physical Sciences & CASTeL, Dublin City University, Dublin 9, Ireland
e-mail: eilish.mcloughlin@dcu.ie

G. Feldman
Department of Physics, George Washington University, Washington DC, USA
e-mail: feldman@gwu.edu

W. Peeters
PONTOn vzw, Boechout, Belgium

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2023
J. Borg Marks and P. Galea (eds.), *Physics Teacher Education*,
Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-44312-1_9

teachers (collective term used to refer to both secondary level teachers and university level instructors) in addressing new challenges and barriers to student participation and engagement in physics education at secondary and university level is critical. Research has shown that a teacher's professional knowledge and skills positively affect instructional quality and student learning (Desimone 2009; Heller et al. 2012; Keller et al. 2017). Many secondary teachers, who were trained more than 10–15 years ago under entirely different conditions, report feeling unconfident and ill-prepared to teach young learners who have a greater knowledge and understanding of digital tools, environmental awareness, or socio-cultural issues (OECD 2020). Crucially, teachers' engagement in professional learning is shown to have a positive influence on their learners' academic achievement in science—and this is increased when teacher professional learning is extended over a period of time and involves the engagement of external experts and opportunities to take part in professional communities of practice (Timperley et al. 2007; Hattie 2009). Research has debated what teacher professional knowledge and skills are needed to facilitate effective teaching and learning. Gess-Newsome (2015) reviews secondary teachers' professional knowledge base for science education in the context of "Pedagogical Content Knowledge" (PCK). This study highlights that the effectiveness of teachers' instructional strategies depends on their understanding of how students learn (a topic) and their awareness of how student learning is affected by other factors, such as the specific educational contexts and students' difficulties/ideas related to that topic. Teachers need to deploy a range of strategies to support individual and differentiated learning in their pedagogical practices. However, opportunities for teacher professional learning vary widely across educational levels and across different countries.

This position paper provides unique insights into how physics teacher education is organized at secondary and university level across different countries. The findings presented in this paper have been collated from contributions to Working Group 6 during the Groupe International de Recherche sur l'Enseignement de la Physique (GIREP) webinar in 2020 and 2021 (GIREP 2021). This paper discusses what strategies are used to support physics teacher education and how physics teachers' needs were identified and addressed in the design and implementation of professional learning programmes. This study presents details of how evidence of the impact of different strategies for teacher professional learning have been collected and evaluated in different countries/programmes.

2 Methodology

The Groupe International de Recherche sur l'Enseignement de la Physique (GIREP) Seminars in 2020 and 2021 hosted by the University of Malta on "Physics Teacher Education—What Matters?", were held as online webinars due to the COVID-19 pandemic. The findings presented in this paper have been collated from contributions to Working Group 6 during these two webinars in the form of oral presentations, survey responses, and focus group discussion sessions during the webinars. Several authors who presented at these webinars also submitted papers for publication in post-webinar proceedings, and the findings from these papers are also included and referenced in this paper.

During the 2020 webinar, working group 6 discussions were focused on four key questions addressing secondary level physics teacher professional learning:

I. What strategies are being used for physics teacher professional learning and what are the strengths and weaknesses of these strategies?
II. What are the key aims, elements, and methods used to support physics teacher professional learning?
III. How are physics teachers' needs identified and addressed in professional learning opportunities?
IV. How do you collect evidence of the impact of different strategies for teaching professional learning?

During the 2021 webinar, working group 6 discussions were expanded to include seven key questions addressing physics teacher professional learning at both secondary and university level:

I. What strategies are used for physics teacher's professional learning at secondary level?
II. What is the requirement for educators/instructors to have a qualification for teaching at university level?
III. What opportunities for teacher professional learning are available—in your school, university, district, region, or country?
IV. What is the focus of teacher professional learning opportunities provided—content, pedagogy, or both?
V. What online resources are available to support teacher professional learning?
VI. What are the possible incentives/barriers to implementing pedagogical innovations?
VII. How is the impact of professional learning of teachers/educators/instructors measured?

Questions I and II were differentiated questions on teacher education at secondary and university level, while questions III–VII were posed in relation to teacher education at both levels. Question I examined opportunities and strategies being used for physics teacher professional learning at secondary level. Question II probed requirements for educators/instructors to have a qualification for teaching at university level and opportunities available to teachers at university level. A summary of the collective responses to each of these seven questions (I–VII) is presented in the following section.

3 Findings

At the beginning of the GIREP 2020 webinar, all webinar participants were asked to complete a short survey to share their opinions on (a) the needs of in-service physics teacher professional learning and (b) the availability of appropriate opportunities for in-service professional learning in their region/country. The responses collected for these two questions are presented in Figs. 1 and 2, respectively and represent responses of 38 individuals from across the globe, and widely varying educational and experience backgrounds. The 38 respondents were from 23 different countries. 18% of the respondents were teaching physics at primary level, 42% were teaching at lower secondary, 53% at upper secondary, and 23% at university level—with some respondents teaching at more than one level. 26% of the respondents had been teaching less than 10 years, 32% had been teaching between 10 and 20 years, 24% had been teaching 20–30 years and 18% had more than 30 years of teaching experience. Most of the respondents agreed/strongly agreed with their need for in-service professional learning to focus on classroom practice (82%) rather than content/science topics (68%) or pedagogy (58%), as shown in Fig. 1. Most of the respondents agreed/strongly agreed that the availability of appropriate opportunities for in-service professional learning focused on content/science topics (71%) rather than pedagogy (53%) or classroom practice (47%), as shown in Fig. 2. These findings highlight the lack of opportunities for this group of international in-service physics teachers ($N = 38$) to engage in professional learning opportunities focused on their greatest identified need, i.e., enhancing their classroom practice.

The following sections present the findings on the seven key questions (I–VII) addressing physics teacher professional learning at both secondary and university level.

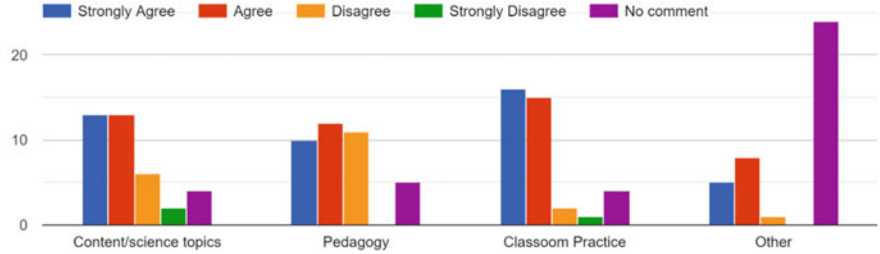


Fig. 1 Survey responses ($N = 38$) to what are your needs for in-service professional learning

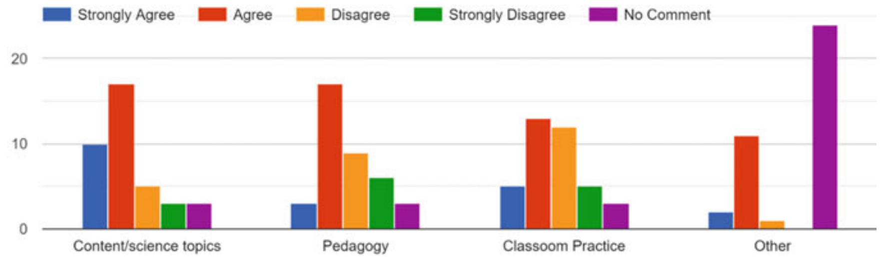


Fig. 2 Survey responses ($N = 38$) to appropriate opportunities available for in-service professional learning

3.1 Question I: What Strategies Are Used for Physics Teacher Professional Learning at Secondary Level?

For teachers at secondary level, a wide range of workshops/courses for professional learning are available. However, these are not always approved by a recognized authority and there is much concern about the lack of quality control, links to curricula, and appropriate use of pedagogies. Many of the professional learning programmes/projects promote the use of active learning and inquiry approaches as a model for professional learning. A more structured strategy for teacher professional learning is proposed based on collaboration between groups of teachers, and possibly university collaboration, in which new ways of teaching (content and/or pedagogy) are collaboratively developed and tested. Examples of strategies adopted in different countries include:

Somogyi et al. (2022) present three different possible, but not necessarily exclusive, ways in which a practicing teacher can acquire the knowledge needed to programme microcontrollers for use in physics education: (a) In-service teacher training: learning from educators, (b) Self-learning materials: learning on one's own and (c) STEAM-projects: learning from the kids.

The Teacher Professional Development Project Neutron stars for training high school teachers, is structured as a course that "*offers teachers a new theme of cutting-edge contemporary research with an active learning methodology, so that they can actively tackle physic*s" (Giliberti et al. 2022). The authors report that the purpose of this programme is "*developing inquiry skills in the teachers themselves and providing them with an example of planning a self-learning path guided and stimulated by questions to be solved and discussions with peers and tutors*" (Giliberti et al. 2022).

Several teacher education programmes have been designed and implemented to support the teaching of quantum physics in high schools. The Plan for Science Degrees (PLS) is a long-standing University project funded by the Italian Ministry of Education which has among its primary objectives, since its foundation in 2004, the collaboration with high schools and teachers, especially aimed at teacher professional development (Lastname et al. 2022). In response to the recent curriculum reform (2012) which considerably expanded the presence of quantum physics topics in the final year programmes, all PLS partner Universities experienced a very strong direct demand from teachers to increase their knowledge and understanding of quantum physics (Lastname et al. 2022). A teaching–learning sequence designed to introduce some fundamental concepts of quantum physics to high school teachers has been developed by Di Mauro et al. (2022). Research-Based Intervention Modules for Teachers of Quantum Mechanics have been developed and implemented by Michelini and Stefanel (2022). Merzel et al. (2022) adopted an approach of "teachers as learners" (Levy et al. 2020) and the method of "active learning" to provide teachers' training toward teaching quantum physics.

The IDIFO (Didactic Innovation in Physics and Guidance) project, which started in 2006 is the contribution to PLS of the Italian research community in physics education made up of 18 cooperating national universities coordinated by the Udine physics education research unit (Buongiorno et al. 2022). The needs of teachers are addressed through school-university collaboration in which the university puts in place proposals for research-based didactic innovation, the school chooses among the proposals offered, contributing to modify them according to its needs and requesting new interventions, initially almost always of content and then also on strategies, which are defined and shared in research-teachers' meetings (in presence or at a distance). These meetings were organized in agreement between researchers and teachers in 1–3 h, depending on the case, on different aspects:

- to define contents to be addressed (for example including connection with school curricula, analysis of exercises, critical analysis of textbooks) and strategies to be adopted
- how to implement and set up the activities
- to establish duration and calendar of formative interventions.

This combination of school and university contributions produced different educational laboratories in which researchers and teachers collaborate to create learning environments for practitioners. Veith and Bitzenbauer (2022) argue that insights into teachers' identity provide researchers with the means to understand teachers' learning and developing processes, and consequently, teacher identity should also be a key consideration in designing teacher professional learning.

Using the framework of educational reconstruction for teacher education (ERTE), Pallotta and Bondani (2022) devised a professional development programme for teachers aimed at identifying the mathematical and physical conceptual difficulties in teaching polarization and at designing a complete teaching–learning sequence (TLS) to be inserted in the curricular programme. The authors adopted a research path consisting of three steps to design, implement and evaluate their programme, namely, (a) training for in-service physics teachers, (b) extracurricular activities with students, and (c) a revised course for teachers.

Bologna et al. (2022) report on the lack of students' ability, at different ages and levels, to construct the mathematical model of physical processes or to describe the physical meaning of mathematical constructs. The authors examined the role of the physics teachers' Pedagogical Content Knowledge (PCK) in the Phys-Math interplay at the early stage of the physics study. The authors present a strategy for creating "*a stable community for professional learning, where teachers discover and become more aware of their PCK and try to design his/her own footprint with a particular attention to the use of Math in Physics, and Physics in Math, taking also into account the different students' age, and the corresponding different cognitive skills, when Physics studies start*".

A valuable source of professional learning opportunities for physics teachers is through European projects that design and implement teaching materials and/or courses. However, there is little information available on how much these materials are used after the project has finished so in general, the impact is not measured. A study by Rigney et al. (2021) shares insights into the designing cross-country professional development in the Erasmus + Linpilcare project (http://linpilcare.eu) that developed and implemented a job-embedded professional development programme centered on practitioner inquiry, professional learning communities, and teachers' use of scholarly literature. The benefits of supporting teacher collaboration through establishing professional learning communities (PLC) with a facilitator, have been promoted in other European Erasmus + projects, e.g., 3DIPhE (www.3diphe.si) and STAMPEd (www.stampedproject.eu) and in national projects, e.g., disciplinary professional learning community (DPLC) in Israel described by Levy et al. (2020, 2021) and Communities of Professional Educators (COPE) in Malta. The basis of these professional communities is that teachers teaching the same subject meet on a regular basis to discuss certain topics, review pedagogical innovations, and discuss how they can implement new approaches to teaching, learning, and assessing physics topics in their practices.

O'Neill and McLoughlin (2022) highlight the needs of novice physics teachers. Their 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 (O'Neill and McLoughlin 2022). Physics in-service teacher training involving a collaboration between secondary level students, physics and mathematics teachers and University researchers has been facilitated through Lesson Study (Capone et al. 2022). The participants follow a lesson study cycle, subdivided into five steps (co-planning, teaching, observation, data analysis, and revision), focused on the interdisciplinary topic of climate change.

Carli and Pantano (2022) report on a learning community approach in the in-service teacher training programme COLLABORA, which is aimed at improving the use of the laboratory in the teaching of physics. Micro-teaching and peer-observation activities were also introduced (Carli and Pantano 2022).

3.2 Question II: What Qualification is Required for Educators/Instructors to Teach at Tertiary/University Level?

In general, educators must have a PhD in physics (or a related discipline) to teach physics at tertiary/university level but are not required to have a teaching qualification for this level. This is quite different from secondary instructors, who must be “certified” in some particular manner. There are ad-hoc opportunities for professional development (PD) for university instructors, but these are purely optional. There are no requirements for instructors to enroll in such PD activities over the course of the year. In fact, most instructors do not know about the availability of such PD programs, and if they do, many do not opt to participate in them.

Most of the PD activities tend to be offered by the universities themselves, usually organized by the local Teaching and Learning Center (or similar office) in the University. There are also PD workshops that are frequently offered at physics education conferences, such as those organized by GIREP or American Association of Physics Teachers (AAPT), but again many university instructors do not attend such conferences. The university faculty members tend to be much more focused on the specific research conferences in their respective sub-fields of physics and generally do not pay much attention to conferences that concentrate on pedagogy.

Probably for most university faculty, the primary means of advancing their pedagogical prowess is through more informal connections with their colleagues in their own departments. Hearing about what one instructor or another is doing in his/her own classes can often serve as an impetus for another instructor to try to adopt those innovations. While it is perhaps not reasonable to classify such exchanges of information as “professional development”, in the long run, it does serve the same purpose.

3.3 Question III: What Opportunities for Professional Learning Are Available—In Your School, University, District, Region, or Country?

In general, secondary level physics teachers can take advantage of professional learning programmes offered by national Universities or teacher education organizations. Universities provide professional learning opportunities for in-service physics teachers based on the outcomes of research programmes or to share new teaching methods. In many countries, national teacher education organizations offer courses annually that are supported by the government to upgrade or maintain teacher registration or qualifications. In addition, European organizations offer courses for in-service teachers as outcomes of Erasmus + projects (e.g., www.pontonvzw.eu).

In terms of professional development activities for university level teachers, short courses or workshops on general pedagogical strategies are often organized by institutional units that are focused on the teaching and learning side of university life. There can also be staff development seminars and some of these events extend their reach into the domain of SoTL (scholarship of teaching and learning). This entails conducting actual pedagogical research, which presumably impacts fewer instructors than the programs aimed at pedagogical innovation in the classroom. As mentioned above, professional societies can also provide opportunities for PD through the various conferences that they sponsor throughout the year. Such workshops can take the form of two-hour sessions offered at GIREP conferences, or even half-day or full day workshops offered on the weekends preceding winter and summer AAPT meetings.

In the United States, a New Faculty Workshop was initiated in 1996 by the AAPT with the intention of providing a general orientation to recently hired physics faculty within the first two or three years of their new positions. This event has run continuously for 26 years (Chasteen and Chattergoon 2020) and has been so successful that it is now offered twice a year, including new astronomy faculty. While the workshop does not focus exclusively on pedagogy, there is certainly a heavy emphasis on these aspects for the new instructors. A European version of this workshop is planned for July 2023 in Switzerland sponsored by the Congressi Stefano Franscini, which is the meeting platform of ETH Zurich. This European workshop will accept up to 70 new instructors from across Europe and will include experienced pedagogical facilitators from Europe and the United States.

There is now a proliferation of online resources available, where short PD "lessons" can be offered to motivated instructors through video training sessions. In this case, as with anything on the internet, the quality of these online resources can vary. Probably the best ones would be videos that are available directly from the AAPT or AIP websites, or else ones that are posted by Teaching and Learning Centers located at universities.

3.4 Question IV: What Is the Focus of Professional Learning Opportunities Provided—Content, Pedagogy, or Both?

At the secondary level, professional learning opportunities for physics teachers focus on content, curriculum-related or pedagogical topics. This is particularly true when new curricula are implemented and in-serving training is mandated for all teachers (Somogyi et al. 2022; Lastname et al. 2022; Pallotta and Bondani 2022).

It is expected that university instructors are very well versed in their own disciplinary fields. With that in mind, the physics content should be fully under control by the instructors. However, without formal training in teaching, it is the pedagogy that could be lacking. Since there is no formal training or certification in that area, professional development tends to focus on pedagogical approaches and strategies.

Instructors know what they themselves know, but it is not so clear that instructors know what the students know or what the students' ideas (misconceptions) are. This awareness is key in higher education, and instructors need to be clued into this concept. Therefore, professional development activities tend to focus on these aspects of pedagogy.

For example, in the SCALE-UP collaborative group-learning approach (Beichner et al. 2007), one successful strategy for training incoming instructors has been to implement an "apprenticeship model" (Feldman 2022) in which new instructors shadow experienced instructors in the classroom during their initial semester. This provides a version of "on the job" training, thus establishing a solid foundation for them to proceed on their own in subsequent semesters. Figure 3 presents an overview of the participation of 24 individual instructors in the SCALE-UP pedagogy (Feldman 2022). Each box represents the first year that an instructor was assigned a SCALE-UP class, over the period 2008–2020. The green boxes indicate instructors who are still actively teaching SCALE-UP classes up to the present day. Finally, the red triangles signify specific instructors who were teaching a SCALE-UP class as recently as the Fall 2021 semester. Note that 14 instructors (out of 24) are still actively teaching SCALE-UP classes, which constitutes a retention rate of 58% over 14 years, and six of these 14 instructors have been teaching in this mode for over 12 years already.

Another example is the use of video analysis of instructors in the classroom to highlight multimodal and rhetorical-didactical characteristics of their teaching to help them enhance the engagement of their students in Venezuela (Rangel et al. 2017). Both examples specifically aim at developing the pedagogical tools of the instructors,

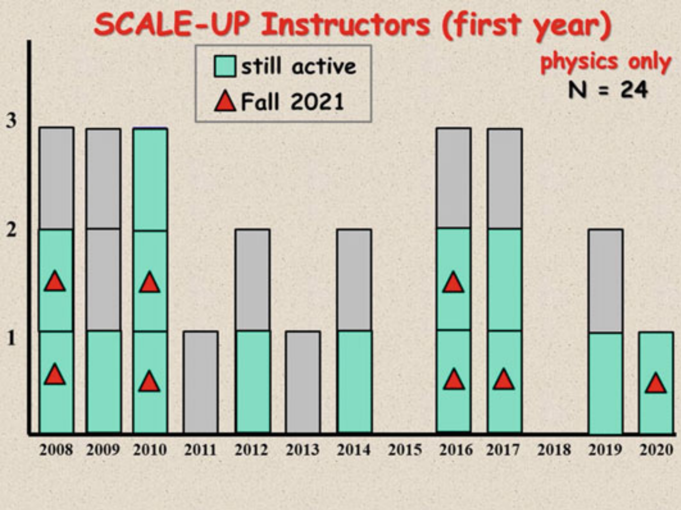


Fig. 3 Summary of first year assignments for 24 individual SCALE-UP instructors. Each instructor is represented either by a grey box (past instructors) or a green box (currently active instructors), and the horizontal axis marks the year in which that person first taught a SCALE-UP class

and they also provide opportunities for the instructors to "learn by doing" in the actual classroom setting.

3.5 Question V: What Online Resources Are Available to Support Teacher Professional Learning?

Online resources for supporting secondary and university educators are interchangeable, although there are some differences. One of the major online resources available to educators is the American Association of Physics Teachers (AAPT)-sponsored PhysPort website (www.physport.org) supported by the U.S. National Science Foundation. This is a project that has been developed over the past several years and it now provides an extensive collection of materials, resources, training videos, etc. for educators. This is openly available to educators at all levels, who are motivated to explore the materials and it is oriented to be particularly advantageous for group settings. It also gives access to concept inventories to measure student learning outcomes and assess the teaching impact of various pedagogical approaches.

In the UK, one can find AdvanceHE (www.advance-he.ac.uk), which is a member-led, sector-owned organization that works with institutions across the world to improve higher education for staff, students, and society. Their strategic goals are to enhance confidence and trust in higher education, address systemic inequalities, and advance education to meet the evolving needs of students and society. In addition, the Institute of Physics (IOP) has a very useful physics education website (www.iop.org/education) which helps promote, develop, and support excellent physics teaching through networks, professional development events, and proven resources.

Another useful resource for educators is PER Central (www.per-central.org) which tends to focus more on physics education research, but there is a very useful Curriculum tab on their website. That tab includes links to course packages, pedagogy guides, student activities, and assessment instruments. The American Physical Society (APS) has a broader education website (www.aps.org/programs/education) which covers programs not only for instructors, but also for staff and students as well. The European Physical Society (EPS) also has an analogous website (www.eps.org/page/education) which covers primary, secondary, and university levels. The American Association of Physics Teachers (AAPT) has a specific resource page (www.aapt.org/resources) dedicated to disseminating guidelines and recommendations for physics teaching, collections of articles from AAPT journals, and an extensive list of international physics education websites.

An analogous website for the science education community in Europe is Scientix (www.scientix.eu) which includes a variety of online resources and links for educators. It aims to promote and support a Europe-wide collaboration among STEM teachers, education researchers, policymakers, and other educational stakeholders to inspire students to pursue careers in STEM. Scientix built an online portal to collect and present European STEM education projects and their results and organized several teacher workshops. Scientix also reached out to national teacher communities and contributed to the development of national strategies for wider uptake of inquiry-based and other innovative approaches to science and math education.

3.6 Question VI: What Are the Possible Incentives/Barriers to Implementing Pedagogical Innovations?

Incentives tend to overlap between the secondary teachers and the university instructors. Many pedagogical innovations increase opportunities for collaborative group work among students, which can lead to improved learning on their part. Such a classroom environment can be more dynamic, which is much more engaging for the students (and the instructor as well) and can also possibly lead in the direction of motivating students toward science. In the end, students can be more satisfied with this type of classroom experience if they are engaged in more interesting and stimulating activities that can help them learn. So, in addition to achieving higher learning gains, the students can thrive in the active environment of the reformed classroom.

Professional development and pedagogical reform can also have the collateral benefit of leading teachers to work together on resources to use during their classes. These resources can then be shared locally at a particular institution, or perhaps posted online for broader dissemination. Moreover, highly motivated teachers and instructors might be interested in making formal presentations about their teaching innovations at pedagogical conferences or possibly submitting papers to journals related to scholarship of teaching and learning (SoTL). Such talks or papers are certain to enhance the academic profile of the instructor at his/her institution. Finally, as one more added incentive, more schools and institutions are beginning to offer special pedagogical awards to teachers and faculty to recognize innovative and enhanced teaching.

On the other hand, several factors can serve as barriers against the implementation of reformed pedagogy. At some level, there is a natural reluctance to change by teachers. The old conventional methods are more familiar and comfortable, and it can be unsettling to introduce new pedagogical innovations. Also, time constraints in class preparation or delivery of classroom material can inhibit an instructor's ability to explore such innovations. Time management is one of the big challenges, and there is a potential risk of running out of time to deliver the full content of the course. Furthermore, in large university lecture classes, these challenges can be magnified, since there are more logistical considerations to deal with in large student populations.

Besides the instructors themselves, there can be resistance to such innovations by other departmental faculty. Some instructors continue to believe that the conventional lecture format has "always worked, so why change it?" These people may oppose pedagogical reforms, believing that they are merely a passing fad and are not needed. Reluctance can also come from lab or technical staff since these innovations might involve some time commitment on their part to assist in the new setups. Finally, there can be a lack of higher level support from the school or institutional administration, probably driven by the concern that such innovations will increase costs. One common theme, which does in fact have some merit, is that these pedagogical reforms might be difficult to evaluate and assess. If the effectiveness of an innovation cannot be measured in some meaningful way, then there is some uncertainty as to the value of the implementation in the first place.

Finally, students can sometimes complain that such pedagogical innovations "make them work" and struggle with the material in class, even though it is intended to help them. While it is true that an initial adjustment period might be necessary while students adapt to their new instructional environment, in the long run, the engaged students will find that they are reaping benefits from such a strategy, as a direct result of their increased efforts. Nevertheless, there will always be a small group of students who do not engage, and their expressed opinions in the end-of-semester course evaluations can appear to reflect negatively on the instructor. Especially for newer instructors, such unfavorable feedback can be a major concern when it comes time for salary increases and/or promotions.

3.7 Question VII: How Is the Impact of Professional Learning of Teachers/Educators/Instructors Measured?

This is a delicate issue for teachers since there is a clear difference between measuring a teacher's professional learning and evaluating a teacher's performance, e.g., for promotion. In many cases, evaluating teacher professional learning is conducted using questionnaires, surveys, interviews, or focus groups. In addition, institutional end-of-year surveys are used to collect feedback on a teacher's performance or peer classroom observations are used.

Working Group 6 discussions revealed, in general, that physics teachers are aware of the components of Pedagogical Content Knowledge and self-efficacy among physics teachers is high. Teachers engage in monitoring the development of students' effective learning. Concerns were raised about the use of student evaluations by authorities in making decisions on renewing teacher contracts and the use of evaluations for measuring teachers' knowledge, skills, etc. Discussions revealed that while teacher/student feedback is collected periodically, the impact of professional learning on teachers or their students is not widely measured. Michelini et al. (2022) proposes that "*the capability of collecting feedback on course impact based on physics education research methods has room for improvement and could benefit from a higher level of coordination between the PLS partner Universities, since the actions undertaken to evaluate the changes in teachers' practices produced by the professional development initiatives were diverse and generally not systematic*".

At university level, a common method used to gauge the effectiveness of professional learning is to assess the student learning outcomes in physics courses. Presumably, the implementation of novel pedagogical approaches will yield enhanced learning gains, and this would certainly justify the value of professional development programs for university instructors. Typically, these assessments are given on a case-by-case basis for each course and tabulated internally within each institution for its own courses and instructors. To some extent, one can also get feedback from end-of-semester course evaluations, but one must be aware that these surveys must be taken in the proper context. They are generally less a measure of pedagogical efficacy and often more a measure of instructor popularity or the difficulty level of a course. Depending on the wording of the evaluation questionnaire, the students might use the survey to complain that the course was "too hard" or that they had "too much work" which is not really a reflection of the teaching quality.

A more widespread impact of professional learning can be inferred by considering changes occurring broadly across many institutions. A large-scale survey of university faculty in the U.S. conducted in 2008 (Dancy and Henderson 2010) indicated that while many instructors were familiar with research-based instructional strategies (RBIS), relatively few employed them in the classroom and often discontinued use after the first attempt. In one example to counter this trend, the Carl Wieman Science Education Initiative (CWSEI) at the University of British Columbia (Wieman et al. 2013) engaged science education specialists to work with faculty to transform courses taught by those faculty. This effort led to a significant reduction in discontinued use of RBISs, mainly attributable to the support offered by the science education specialists who helped faculty customize the RBIS and provided advice to address implementation difficulties. Following up on the earlier 2008 survey, a new survey by the same authors was conducted in 2019, and some initial data have been recently published (Apkarian et al. 2021). These results suggest that the use of RBISs by physics faculty has greatly increased over the past 11 years, and more importantly, the persistence of this usage has been firmly established—that is, a much higher fraction of faculty who initiate an RBIS continue to use that strategy in the classroom. In that sense, a general movement of professional development for faculty, by whatever means it was accomplished across institutions, appears to have had a big positive effect on the dissemination and implementation of innovative pedagogical approaches.

4 Conclusions

The findings presented in this paper have been collated from contributions to Working Group 6 during the two webinars of the Groupe International de Recherche sur l'Enseignement de la Physique (GIREP) Seminars in 2020 and 2021 on "Physics Teacher Education—What Matters?". From contributions and discussions at the 2020 and 2021 GIREP webinars, we draw conclusions on the strategies used for enhancing physics teacher professional learning at school and university levels.

We conclude that the majority of the strategies of professional learning available for teachers at secondary level are motivated by the content of the (new) curriculum subject. The impetus for teacher professional learning is in the hands of researchers and universities and is aligned with their interests and motivation. This does not necessarily mean that there is a mismatch with the teachers' needs for professional learning. The strategies used for facilitating professional learning are very diverse and dependent on the context of the programme/course. In general, there is governmental support for teacher professional learning and teachers have access to a lot of professional learning opportunities and access to online resources. However, most professional learning initiatives are limited in time and lack follow-up. The influence and sustainability of teacher professional learning is not guaranteed and not often measured.

For university physics teachers/instructors, we conclude that formal professional development opportunities through institutional programs or conference workshops are not widely exploited. It appears that most advances in the adoption and implementation of innovative pedagogy occur on a very local level, through conversations and examples exchanged among faculty in a specific department at an individual institution. Usually, these changes are inspired by one (or a few) faculty member(s) who motivate the changes and assist their colleagues in bringing these innovations into their own classrooms. This "informal" style of professional learning is not rigidly structured and is difficult to characterize. One of the more organized (and successful) programs for university faculty professional development is the concept of the New Faculty Workshop (Chasteen and Chattergoon 2020). The key is to catch the young faculty at an early stage and present them with innovative teaching strategies from the outset. Providing a cohort of implementers through some sort of network or online faculty learning community (Dancy et al. 2019) can help support the effort and increase the probability for a sustained pedagogical intervention. The option to partner university faculty with STEM education specialists (or at least, other faculty with direct experience in these innovations) can be enormously beneficial in terms of sharing their expertise and consulting on implementation strategies. The impact of the approach outlined above has been quantified to some extent in cross-institutional surveys (Dancy and Henderson 2010), and new data will shortly be forthcoming to illustrate the expansion of pedagogical reforms in a variety of settings. While those data may promise to show what has been accomplished over the past 10–11 years, a missing element would be how these gains have been realized—that is, what sort of professional development methods or strategies are responsible for these gains. In addition, we have discussed barriers and incentives for pedagogical innovations, yet it remains to be seen whether barriers are being broken down or incentives are becoming more compelling. Probably the answer is somewhere in the middle, with a little bit of both contributing to the overall picture.

Acknowledgements The authors would like to acknowledge the contributions of Working Group 6 participants during the Groupe International de Recherche sur l'Enseignement de la Physique

(GIREP) Seminars in 2020 and 2021 hosted by the University of Malta on "Physics Teacher Education—What Matters?" We particularly want to acknowledge the contributions of Dr. David Sands as Working Group 6 leader for the 2020 Webinar.

References

Apkarian N, Henderson C, Stains M, Raker J, Johnson E, Dancy M (2021) What really impacts the use of active learning in undergraduate STEM education? Results from a national survey of chemistry, mathematics, and physics instructors. PLoS ONE 16(2):e0247544. https://doi.org/10.1371/journal.pone.0247544

Beichner R et al (2007) The student-centered activities for large enrollment undergraduate programs (SCALE-UP) project. In: Redish EF, Cooney PJ (eds) Research-based reform of university physics. American Association of Physics Teachers, College Park. Reviews in PER, vol 1. http://www.per-central.org/document/ServeFile.cfm?ID=4990

Bologna V, Longo F, Peressi M, Sorzio P (2022) Monitoring PCK physics teachers' strategies for math and physics languages integration: the teacher footprint. J Phys: Conf Ser 2297:012034. https://doi.org/10.1088/1742-6596/2297/1/012034

Buongiorno D, Michelini M, Santi L, Stefanel A (2022) Answering to physics teachers' needs in professional development. J Phys: Conf Ser 2297:012033. https://doi.org/10.1088/1742-6596/2297/1/012033

Capone R, Adesso, MG, Fiore O (2022) Lesson study in physics education to improve teachers' professional development. In: Borg Marks J, Galea P, Gatt S, Sands D (eds) Physics teacher education. Challenges in physics education. Springer, Cham. https://doi.org/10.1007/978-3-031-06193-6_9

Carli M, Pantano O (2022) The impact of a two-year in-service teacher training programme on the use of the laboratory and self-efficacy beliefs. In: Borg Marks J, Galea P, Gatt S, Sands D (eds) Physics teacher education. Challenges in physics education. Springer, Cham. https://doi.org/10.1007/978-3-031-06193-6_8

Chasteen SV, Chattergoon R (2020) Insights from the physics and astronomy new faculty workshop: how do new physics faculty teach? Phys Rev Phys Educ Res 16(2):020164. https://doi.org/10.1103/PhysRevPhysEducRes.16.020164

Dancy M, Henderson C (2010) Pedagogical practices and instructional change of physics faculty. Am J Phys 78(10):1056–1063. https://doi.org/10.1119/1.3446763

Dancy M, Lau AC, Rundquist A, Henderson C (2019) Faculty online learning communities: a model for sustained teaching transformation. Phys Rev Phys Educ Res 15(2):020147. https://doi.org/10.1103/PhysRevPhysEducRes.15.020147

Desimone LM (2009) Improving impact studies of teachers' professional development: toward better conceptualizations and measures. Educ Res 38:181e200. https://doi.org/10.3102/0013189X08331140

Di Mauro M, Esposito S, Naddeo A (2022) Teaching quantum physics in the footsteps of Einstein. J Phys: Conf Ser 2297:012036. https://doi.org/10.1088/1742-6596/2297/1/012036

Feldman G (2022) How to promote and sustain active-learning pedagogical reforms in University Physics through instructor apprenticeship. J Phys: Conf Ser (in press)

Gess-Newsome J (2015) A model of teacher professional knowledge and skill including PCK. In: Berry A, Friedrichsen PJ, Loughran J (eds) Re-examining pedagogical content knowledge in science education. Routledge, NY, p 28

Giliberti E, Perottie L, Giliberti M (2022) Neutron stars for training high-school teachers. J Phys: Conf Ser 2297:012029. https://doi.org/10.1088/1742-6596/2297/1/012029

GIREP (2021) Groupe International de Recherche sur l'Enseignement de la Physique. https://www.um.edu.mt/event/girep

Hattie JAC (2009) Visible learning. A synthesis of over 800 meta-analyses relating to education. Rutledge, New York

Heller JI, Daehler KR, Wong N, Shinohara M, Miratrix LW (2012) Differential effects of three professional development models on teacher knowledge and student achievement in elementary science. J Res Sci Teach 49(3):333–362. https://doi.org/10.1002/tea.21004

Keller MM, Neumann K, Fischer HE (2017) The impact of physics teachers' pedagogical content knowledge and motivation on students' achievement and interest. J Res Sci Teach 54(5):586–614. https://doi.org/10.1002/tea.21378

Michelini et al (2022) An overview of physics teacher professional development activities organized within the Italian PLS-physics plan over the past five years. J Phys: Conf Ser 2297:012030. https://doi.org/10.1088/1742-6596/2297/1/012030

Levy S, Kapach Z, Magen E, Yerushalmi E (2020) Re-defining lab norms via professional learning communities of physics teachers. In: Wolf S, Bennett M, Frank B (eds) Physics education research conference proceedings, Washington, DC

Levy S, Bagno E, Berger H, Eylon B (2021) Professional growth of physics teacher-leaders in a professional learning communities program: the context of inquiry-based laboratories. Int J Sci Math Educ. https://doi.org/10.1007/s10763-021-10217-7

Merzel A, Weissman, EY, Katz, N, Galili I (2022) Toward teacher training for teaching quantum physics in high. In: Borg Marks J, Galea P, Gatt S, Sands D (eds) Physics teacher education. Challenges in physics education. Springer, Cham. https://doi.org/10.1007/978-3-031-06193-6_12

Michelini M, Stefanel A (2022) Implementing research-based intervention modules for teachers of quantum mechanics. In: Borg Marks J, Galea P, Gatt S, Sands D (eds) Physics teacher education. Challenges in physics education. Springer, Cham. https://doi.org/10.1007/978-3-031-06193-6_7

O'Neill D, McLoughlin E (2022) What do novice physics teachers identify as their problems of practice? In: Borg Marks J, Galea P, Gatt S, Sands D (eds) Physics teacher education. Challenges in physics education. Springer, Cham. https://doi.org/10.1007/978-3-031-06193-6_10

OECD (2020) TALIS 2018 results (volume I): teachers and school leaders as lifelong learners. TALIS, OECD Publishing, Paris. https://doi.org/10.1787/1d0bc92a-en

Pallotta F, Bondani M (2022) Teaching optical polarization in high schools: mathematics and experiments. J Phys: Conf Ser 2297:012032. https://doi.org/10.1088/1742-6596/2297/1/012032

Rangel N, Castells M, Castello J (2017) Multimodality of explanation in physics class. Literacy engineering students. https://periodicos.uniformg.edu.br:21011/periodicos/index.php/conexaociencia/article/view/839/945

Rigney J, Dana NF, Vanderhauwaert R (2021) Cross-country collaboration in pursuit of powerful teacher professional learning: lessons from the European Union. Teach Teach Educ 97:103212. https://doi.org/10.1016/j.tate.2022.103719

Somogyi A, Kelemen A, Mingesz R (2022) Low-cost high-resolution measurements of periodic motions with Arduino in physics teacher in-service education. J Phys: Conf Ser 2297:012031. https://doi.org/10.1088/1742-6596/2297/1/012031

Timperley H, Wilson A, Barrar H, Fung I (2007) Teacher professional learning and development. Best evidence synthesis iteration [BES]. New Zealand Ministry of Education, Wellington

Veith JM, Bitzenbauer P (2022) Teacher identity in science education—results of an empirical study on first- and third-person narratives. J Phys: Conf Ser 2297:012035. https://doi.org/10.1088/1742-6596/2297/1/012035

Wieman C, Deslauriers L, Gilley B (2013) Use of research-based instructional strategies: how to avoid faculty quitting. Phys Rev Spec Top Phys Educ Res 9(2):023102. https://doi.org/10.1103/PhysRevSTPER.9.023102

Initial Teacher Training

Prospective Primary Teachers Education on DC Electrical Circuits

Giuseppe Fera and Marisa Michelini

Abstract Prospective Primary Teachers (PPT) education requires different kinds of integrated activities to produce competence in building learning environments and, in particular, to produce conceptual change from the common ideas to the scientific one. Implicit conceptual knots of pupils are often present in PPT ideas on phenomena. Test in/out and research-based proposals as formative tools for Pedagogical Content Knowledge (PCK) seem useful to identify the learning knots of specific topics and support professional development of PPT. An in–out-test on DC electrical circuits was developed, also using the documentation of research with 7–12 year old students and administrated before and after a formative module based on research-based paths. The test-in stimulated reflection on the conceptual knots highlighted in the literature and the learning gain of the formative module emerged in test-out data analysis offering guidelines for PPT pre-service education.

1 Introduction

A wide literature (Kaltakci Gurel et al. 2015) investigated students' common ideas on physics topics. The Prospective Primary Teachers (PPT) basic knowledge is that from the learning outcomes of many different kinds of secondary schools. Literature highlights that secondary students' explanations of elementary phenomena in direct current (DC) electrical circuits evidenced the presence of widespread and persistent learning difficulties: students use spontaneous models such as the unipolar model, in which the circuit is not closed; the idea of clashing currents, in which the current in the branches of a battery-bulb circuit are in opposite directions; the idea of consuming current in the light bulb (Osborne 1983; Psillos 1998; Borges and Gilbert 1999).

G. Fera (✉) · M. Michelini
Physics Education Research Unit, University of Udine, Via Delle Scienze 206, 33100 Udine, Italy
e-mail: giuseppe.fera@uniud.it

M. Michelini
e-mail: marisa.michelini@uniud.it

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2023
J. Borg Marks and P. Galea (eds.), *Physics Teacher Education*,
Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-44312-1_10

In the context of PPT education, the identification of common ideas is an important step for teachers to develop a strong awareness of the presence of such conceptions in children and of how these conceptions can be overcome in teaching practice, creating learning environments. In the implementation of the Metacultural, Experiential and Situated (MES) (Michelini 2020) model adopted in the Physics Education course for PPT in the University of Udine, the Metacultural formative module centered on research-based paths appear relevant for science matter knowledge acquisition, but not enough to reach the required competence to identify and to face conceptual knots with children. In addition, in the case of DC electrical circuits three conceptual perspectives influence ideas and learning aspects in science education and teacher education: (1) the functional one of the equivalent circuit, (2) the link between electrostatics and electrodynamics, (3) the link between macro/micro descriptive levels. PPT education involves the study of the ways in which the integration of subject matter and pedagogical education offers professional competences for primary science education, particularly those professional skills related to the use of strategies in context, aimed to overcome children's conceptual knots and/or activate interpretative models fostering scientific thinking. The involvement of PPT in the analysis of spontaneous reasoning based on different models helps them in building disciplinary knowledge, epistemological understanding, and competence in scientific knowledge construction and evaluation practices (Lehrer and Schauble 2006; Schwarz and White 2005; Stewart et al. 2005).

The global problem to be faced regarding teacher education for physics education is how to educate teachers to enable them to offer scientific activities to primary school students, producing conceptual learning, overcoming learning knots and adopting different approaches to build learning environments. The skills that teachers need to gain are primarily how to identify personal learning knots and how to make children overcome the learning difficulties emphasized by the educational research (Campbell and Neilson 2012); moreover, the teachers must be familiar with the proposed paths in the educational literature (Licht 1991; Tveita 1997; Stocklmayer 2010) and with the analysis of the common children's ideas on the subject (Kibble 1999; Fera and Michelini 2012).

In this research, we analyze the role of a test-in/out in focusing attention on conceptual knots and learning outcomes to be produced by the approach based on different educational paths. Moreover, the PPT ideas are explored, seeking to understand how these ideas would help address the learning knots with children.

2 Research Questions

The first part of the MES model (Michelini 2020) adopted for PPT professional education discusses the physics concepts through the analysis of educational paths in which the main research-based educational results are shown, and the ways in which the conceptual knots identified by the literature are addressed. To focus the attention of PPT on conceptual aspects involved in the topic of DC circuits and to individuate the main difficulties of PPT, a test-in/out was administrated and results were used to reinforce reflection on the main aspect of conceptual change.

The research questions are:

RQ1 How do PPT interpret the situations related to the conceptual knots highlighted in the literature?

RQ2 How does the analysis of DC circuits through a research-based learning path centered on conceptual knots change the vision and the way of dealing with concepts with children?

RQ3 How can the relationship between macro and micro levels of interpretation be supported?

3 Research Methodology

The same test was administrated for individual distance answers both at the beginning and at the end of the Metacultural phase of MES model of the discussion of educational paths on DC circuits. The test was offered as a support to focus relevant aspects in the topic, as an interactive part of the teaching modality and not in a mandatory way and it includes 29 questions. 16 of the questions are multiple-choice questions (4 alternatives, one of which is correct) and 13 are open questions. The test was given to PPT, again with individual remote response methods. The multiple-choice questions were followed by open-ended questions on: How would you explain the concept to the children? or: How would you discuss the problem posed in the previous question in class?

The answers to the test were analyzed in order to individuate the ideas of PPT, in particular the perspectives and models they use to interpret the phenomena occurring in the circuits and how they plan to attach the conceptual knots and explanations with children.

The conceptual knots focalized into the tests are the following (Fera and Michelini 2012): (1) bipolarity of battery and bulb; (2) closure of the circuit; (3) independence of the circuit functioning from the position of the elements (topological problem); (4) role of wire and battery; (5) current and the charge carriers in the wire; (6) microscopic interpretation of Ohm's law; (7) identification of connections in series and parallel.

The passage of the electric current is represented from the microscopic point of view according to the Drude model (Drude 1900). From a macroscopic point of view, the intensity of the current is detected by observing the different brightness of the bulbs inserted in the circuits in different situations, with wires of different materials, or with different lengths or sections, and finally in the circuits in series or parallel. The bulbs were chosen in such a way that the effect of the internal resistance of the battery was insignificant.

The rationale of the Metacultural part in between test-in/out is structured as an Inquiry Based Learning (IBL) path using simple circuits, homemade by means of light bulbs, wires and batteries (without lamp holders) based on the following points/

problems: (1) How can a battery be connected to a light bulb so that the latter turns on? (2) What is the role of wires and battery? (3) How can we differentiate between electrical insulators and conductors? (4) How can we recognize topologically equivalent circuits? (5) How does electrical resistance depend on the geometrical parameters of the wire? (6) How can we differentiate between series and parallel connections?

4 Data Analysis

The answers to the questions of the in/out-test were different: 108 is the number of responders of the in-test and 89 is that of the out-test. The percentage difference between those numbers is 18% of the sample, which is quite high. The aim was to identify the difficulties before approaching the DC topic in the PPT course and to detect to what extent the metacultural phase helps to overcome them. Obviously, for the comparison, the data in percentages were considered. In Figs. 2, 4, 5, 6, 7, 8 and 9 the percentage of total responders is higher than 100% because multiple responses were accepted.

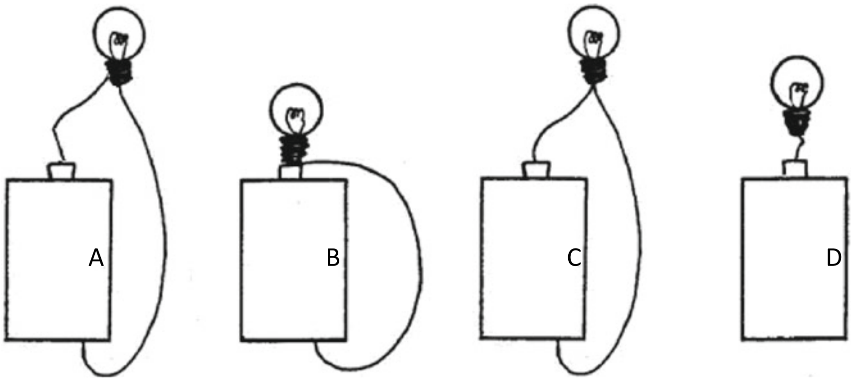


Fig. 1 Circuits of the Question D1

D1. The children have a battery, wires and a light bulb at their disposal. To turn on the light bulb connect the wires as in Fig. 1 (Osborne 1983) that represent the circuits A, B, C, and D. Select in which of them the bulb lights up.

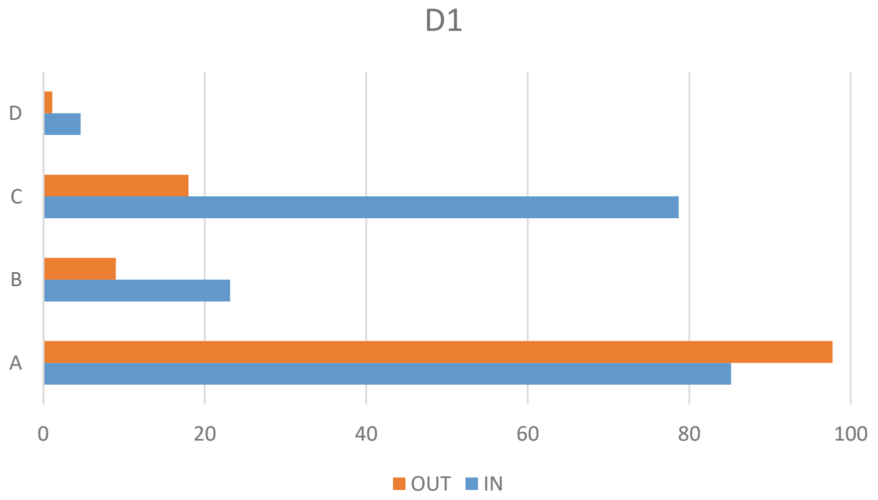


Fig. 2 Results of the Question D1

The strong basis of the initial ideas is on (A, C): two wires that start from the two poles of the battery (80%), which evolve into the correct answer A: each wire goes to different ends of the bulb. There remains a minority of answers indicating that what is required is only that each pole of the battery be connected to the bulb (10–20%).

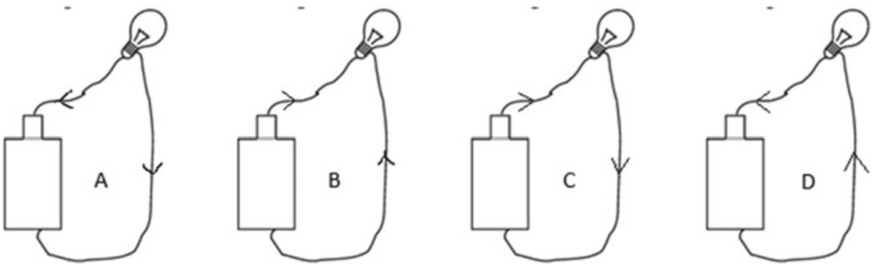


Fig. 3 Circuits of the Question D4

D4. In Fig. 3 (Osborne 1983) the arrows indicate the direction of the current in the wires when the light bulb is on. Indicate the correct representation among the four A, B, C, and D shown in Fig. 3.

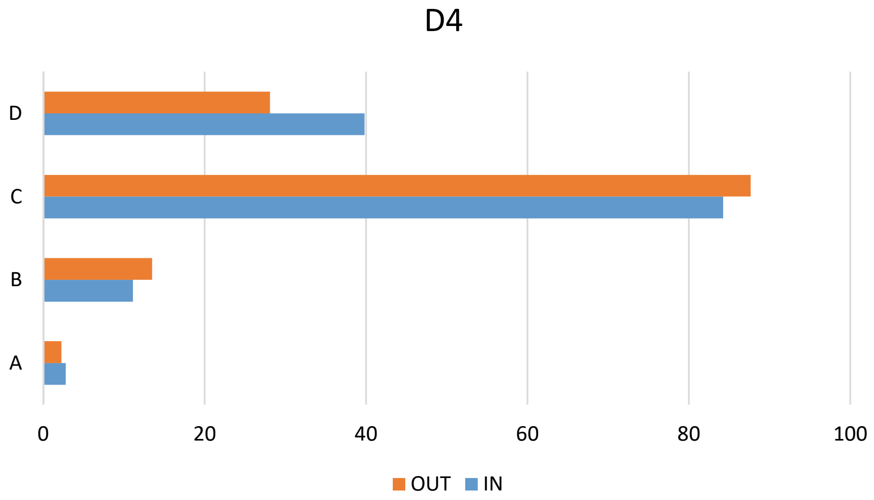


Fig. 4 Results of the Question D4

No significant change with respect to the correct answer C. When the directions are inserted in the circuit, the incoming answers are mainly correct and the outgoing ones are recovered. Answers for the other options remain a minority, with option D, concerning an idea of current circulation from the negative pole to the positive one in the circuit being more chosen than the rest. The small number of answers for option B indicates the residual presence of the clashing current model, well known in the literature (Osborne 1983).

D7. I have a circuit consisting of a battery and a bulb. What is the role of the battery?

(A) Generate a current;
(B) Producing electrons;
(C) Generate a potential difference;
(D) Producing electricity.

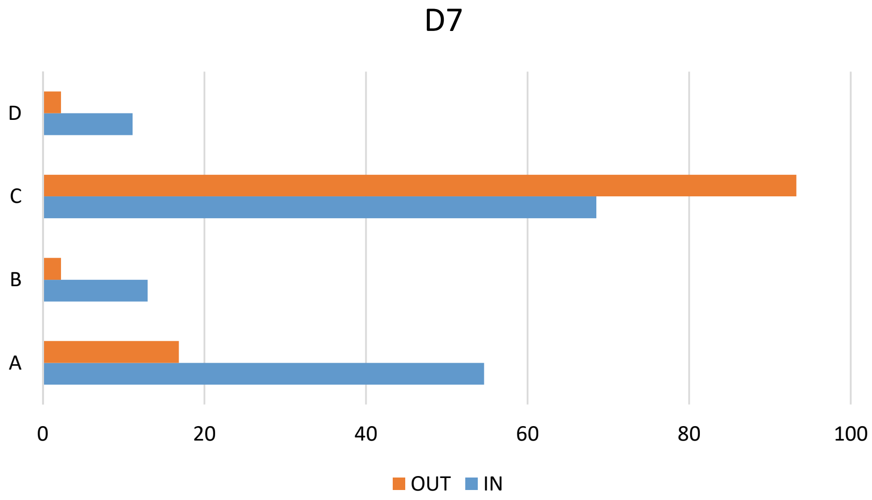


Fig. 5 Results of the Question D7

A significant change of ideas (38%) is seen from A to the correct answer C. 24% of other responses are also seen to change to option C. The biggest change concerns the type A and B responses. Answer A is the dominant one in student studies and this also results at the beginning of the test for the PPT. Moreover, it is a persistent idea, as 18% of the responders continue to select it.

D13. Different materials are used to close the circuit consisting of a battery and a light bulb instead of the switch. How do you explain the different brightness of the bulb?

(A) Different materials disperse energy in different ways
(B) Different materials absorb energy in different ways
(C) Different materials have different numbers of electrons
(D) Different materials have different electron mobility

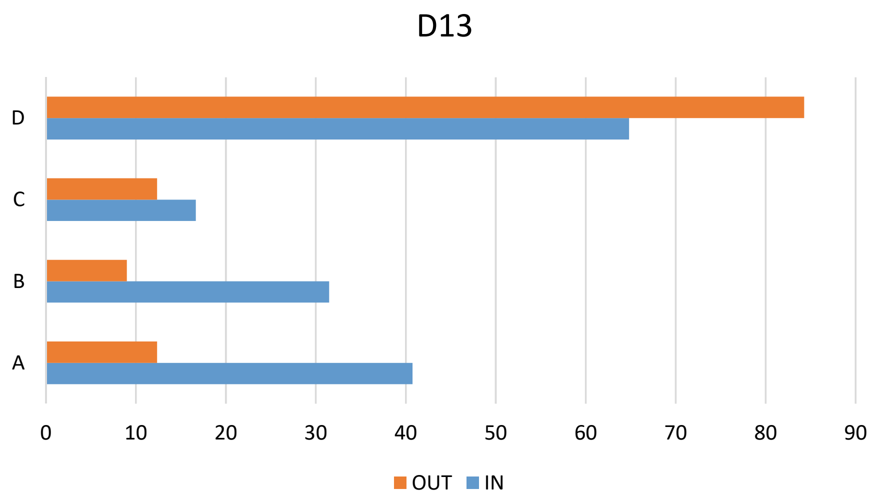


Fig. 6 Results of the Question D13

Significant migration of answers to the correct answer D: more than half of the students changed answers A, B, C (56%) and D was chosen by 84% of the PPT. The migration from A to D highlights the overcoming of a sequential conduction model. The macroscopic vision present in the A and B types of input responses is not maintained, perhaps due to the fact that it was not explored in the lesson. It should be noted that models based on energy are initially preferred but then dropped after the discussion of the issue from a microscopic point of view.

D15. Copper wires of different lengths and the same cross-section are used to close the circuit. How do you explain that the brightness of the bulb is greater with the short wire?

(A) Because the bulb is closer to the battery
(B) The short wire has fewer obstacles to the passage of the current
(C) The short wire has less energy dispersion
(D) The resistance of the short wire is lower

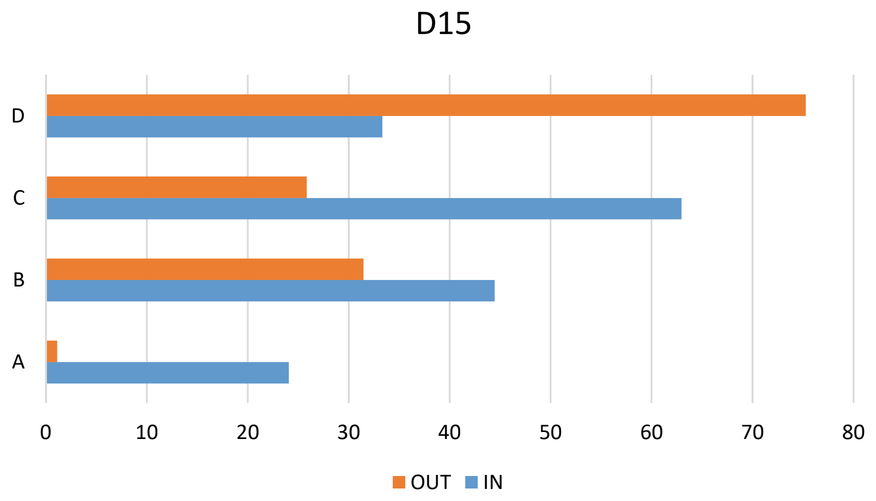


Fig. 7 Results of the Question D15

Significant migration of answers to the correct one D again. The B decreased by only 13%, highlighting that the microscopic vision of the lattice ions as obstacles to the passage of current favors a reading of the phenomenon in which the resistance is proportional to the length of the wire, although a more in depth analysis would lead to a different relationship (Horsfield 2005). The permanence of about 25% of C responses denotes the initial spontaneous tendency to interpret the processes in the circuits in terms of energy. The same idea also emerges in the previous question D13.

D17. Copper wires of different cross-sections and equal lengths are used to close the circuit. How do you explain that the brightness of the bulb is greater with the thick wire?

(A) The thick wire has less current leakage
(B) The thick wire has fewer obstacles to the passage of the current
(C) The thick wire has less energy dispersion
(D) The resistance of the thick wire is lower

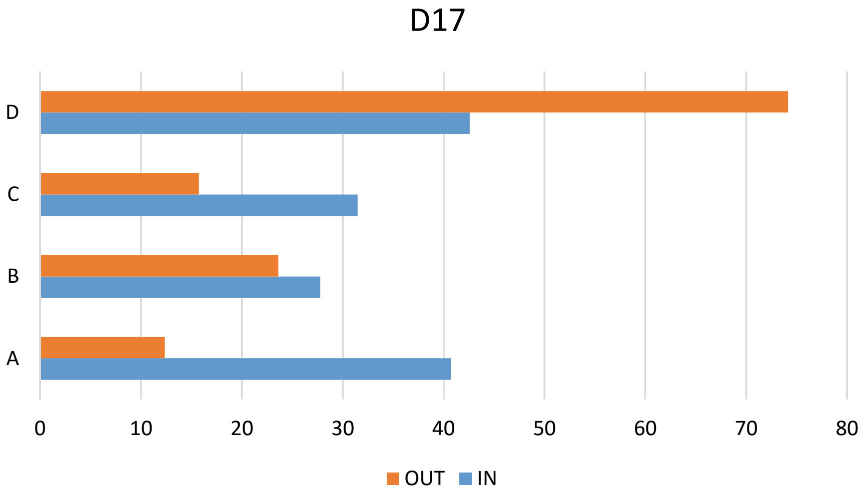


Fig. 8 Results of the Question D17

75% of the students correctly answer D in the out-test. 29% of the students changed from answer A: this confirms the overcoming of the sequential model in favor of the macroscopic vision of resistance. The permanence of C and B answers, between 20 and 30%, confirms the persistence of an energy type spontaneous interpretation in the first case and the adoption of the resistance model, based on the role of obstacles to the flow of charges in the second case. We realize that PPT have a great need to discuss alternative models in depth and not just to learn the scientific one.

D23. Two bulbs are connected in parallel. How do you expect their brightness to be?

(A) The farthest from the battery is brighter than the other
(B) They have the same brightness
(C) The one closest to the battery is brighter than the other
(D) They have different brightness

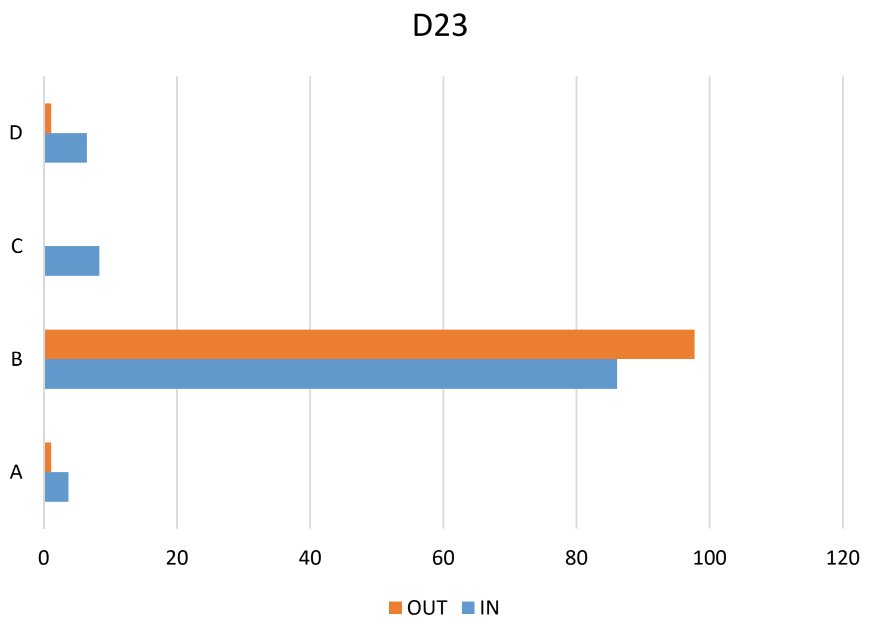


Fig. 9 Results of the Question D23

No significant change: the PPT are oriented towards the correct answer B already.

D26. Unscrew one of the two bulbs connected in parallel. How do you expect the brightness of the other to vary?

(A) It stays the same
(B) It increases if it is closer to the battery
(C) It goes out
(D) It decreases

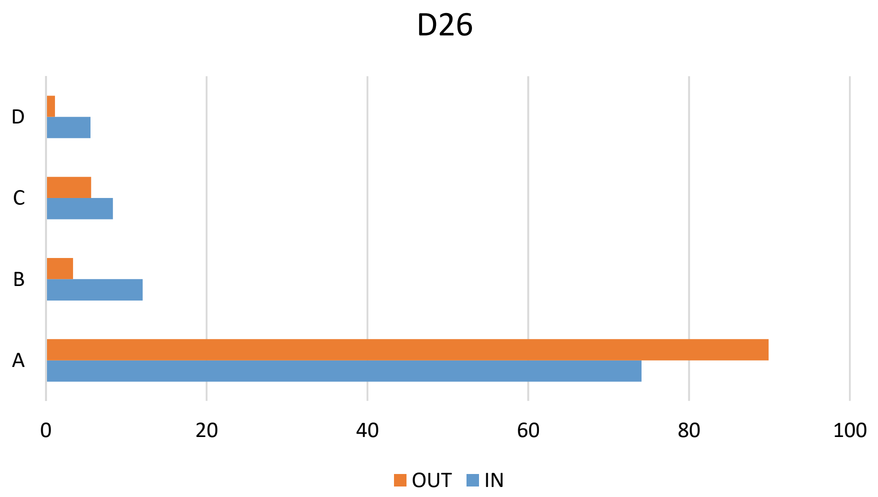


Fig. 10 Results of the Question D26

Also, in this case, the A answers show that the reasoning is correct even in the early stage. A minority of students use the sequential model (B) on incoming answers.

D27. Two bulbs are connected in series. Why do they have the same brightness?

(A) The speed of the particles is the same
(B) The current is the same
(C) They receive the same voltage from the battery
(D) For the law of communicating vessels

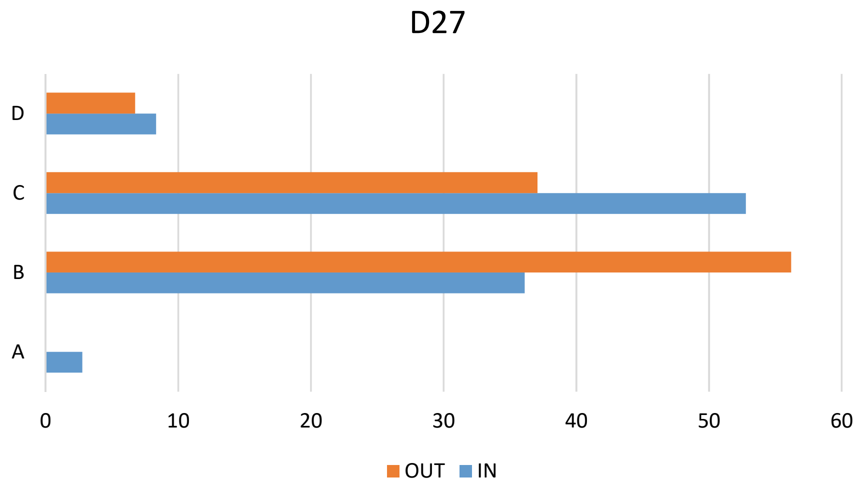


Fig. 11 Results of the Question D27

The results show a dominance of the answers B (correct) and C, with a students' view shifting from voltage to current leading to a correct interpretation of the brightness of the bulbs. The 37% permanence of the C responses indicates a poor understanding of the physical quantity being considered.

D28. Unscrew one of the two bulbs connected in series. How do you expect the brightness of the other to vary?

(A) It stays the same
(B) It increases if it is closer to the battery
(C) It goes out
(D) It decreases

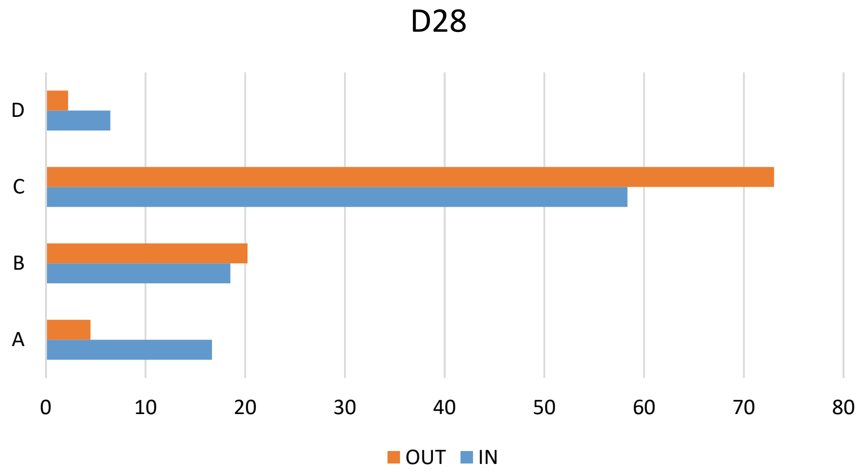


Fig. 12 Results of the Question D28

73% of the students correctly chose the answer C (See Fig. 12). Changes from the preliminary answers A or D are evidenced, highlighting that the meaning of ‘closed circuit’ has been clarified. This question is similar to the D26 but, surprisingly, the sequential model (B) is adopted by almost a fifth of the students and it persists even after the lesson.

5 Concluding Remarks

The professional education of Prospective Primary Teachers (PPT) is a complex task, especially because it concerns the integration of disciplinary competence, often very poor, with pedagogical and didactic ones, often addressed in general terms. In our previous studies, the choice to address the issue through the critical discussion of research-based educational proposals has proved to be motivating and suitable for the scope, but the PPT, re-elaborating the proposals during lessons, for the didactic projects to implement in the classroom with children, highlighted gaps especially on the conceptual nodes, on those elements of difficulty for the children whose critical aspects are underestimated. In this study we have made the participation of PPT in the problems more active by involving them in an in–out-test studied on the critical elements of the literature to focus their attention both on the relevant conceptual aspects and on the students’ learning problems of the topic electrical circuits, analyzing at the same time the effectiveness of this stimulus in overcoming any critical issues of the PPT themselves.

The responses of 108 PPT in the test-in and 98 PPT in the test-out were compared in percentages. It emerged in particular in the test-in results that many of the difficulties of the children detected in the literature are also critical aspects for PPT, such as the meaning of closed circuit, the role of the equivalent circuit and topological deception, the role of the components in a simple circuit and the prospects of analysis of circuits in series and in parallel (RQ1). Among the main results, it emerged that there was a significant role of the tests and corresponding conceptual gain in the analysis of the characteristics of a circuit, both regarding the polarities of the bulb and the role of the battery to deliver a voltage rather than current. The typical topological deception is in particular outdated as it emerges from the answers to the questions D23 and D26. The significance of the circuit and conduction properties of materials also shows an improvement. Particularly effective in appropriating the characteristics of the different connections in the circuits are situations in which the evaluation of the effects is requested with small modifications of circuits in series and in parallel (RQ2). The analysis of microscopic processes based on evidence of macroscopic effects is favored if we consider changes in the material and section of conduction wires (RQ2, RQ3). The request to account for microscopic processes in particular, makes the answers more correct and responsive to macroscopic observations and favors attention to be able to account for the overcoming of the ideas of current circulation highlighted in the literature such as that of consumption. The current is conceived in terms of outcome linked to the characteristics of the circuit, rather than an entity generated by the battery and possibly consumed in the flow (RQ3). Finally, the idea of the “numerousness” of charge carriers appears which, together with mobility, forms the basis of the physical description of the electrical properties of materials.

Acknowledgements Authors thank Marco Giliberti for the help in discussions on the topics treated and in presenting the paper.

References

Borges AT, Gilbert JK (1999) Mental models of electricity. Int J Sci Educ 21(1):95–117

Campbell T, Neilson D (2012) Modeling electricity: Model-based inquiry with demonstrations and investigations. The Physics Teacher 50(6):347–350

Drude P (1900) Zur Elektronentheorie der Metalle; II. Teil. Galvanomagnetische und thermomagnetische Effecte. Annalen der Physik. Springer, ed. (2009). “Free” Electrons in Solids. Free electrons in solid. 308(11):369, pp 135–158. https://doi.org/10.1007/978-3-540-93804-0_6. ISBN 978–3–540–93803–3.

Fera G, Michelini M (2012) Pupils’ ideas exploration on metal electrical transport models in the informal context of an hands-on exhibit Latin American. J Phys Educ 6(1):198–207

Horsfield A, Meso, Nanostructures (2005) Encyclopedia of condensed matter physics eds Bassani F, Liedl GL, Wyder P, Elsevier pp 347–353

Kaltakci Gurel D, Eryilmaz A, McDermott L CA (2015) Review and comparison of diagnostic instruments to identify students’ misconceptions in science. Eurasia J Math, Sci Technol Educ, 11 5 989–1008

Kibble B (1999) How do you picture electricity? Phys Educ 34(4):226–229

Lehrer R, Schauble L (2006) Cultivating Model-Based reasoning in science education. Camb Handb Of: Learn Sci ed Sawyer RK Cambridge University Press pp 371–387

Licht P (1991) Teaching electrical energy, voltage and current: an alternative approach. Phys Educ 25 pp 271–277

Michelini M (2020) Dialogue on primary, secondary and university Pre-service teacher education in physics research and innovation in physics education: two sides of the same coin eds Guisasola J, Zuza K Springer pp 37–51

Osborne RJ (1983) Towards modifying children's ideas about electric current 1983 Res Sci Technol Educ, 1(1) pp 73–82

Psillos D (1998) Teaching introductory electricity Connecting research in physics education with teacher education eds Tiberghien A, Jossem EL, Barojas J, Int Comm Phys Educ

Schwarz CV, White BY (2005) Metamodeling knowledge: Developing students' understanding of scientific modeling. Cogn Instr 23(2):165–205

Stewart J, Cartier JL, Passmore CM (2005) Developing understanding through model-based inquiry How students learn eds Donovan MS, Bransford JD, Washington, DC: National Research Council pp 515–565

Stocklmayer S (2010) Teaching direct current theory using a field model. Int J Sci Educ 32(13):1801–1828

Tveita J (1997) Constructivistic teaching methods helping students to develop particle models in science. In: The Fourth International Seminar on Misconceptions Research, http://www.mlrg.org/proc3pdfs/Tveita_KineticParticleModel.pdf

Encouraging a Laboratory Approach in Physics Teaching: A Case Study for Preservice Elementary Teachers at Roma Tre University

Adriana Postiglione, Ilaria De Angelis, and Enrico Bernieri

Abstract Science especially physics, often arouses fear and a sense of inadequacy among aspiring primary school teachers, which results in low confidence and low teaching self-efficacy beliefs. To contribute towards improving this situation, at Roma Tre University we conducted a series of lessons for the Physics Education Course for the Primary Education Science Department that improved students' confidence in dealing with physics topics and experimental activities. In this paper, we analyse the lessons we proposed and the positive feedback we received.

1 Introduction

In recent years, numerous studies have shown how science subjects, especially physics, often put a strain on preservice elementary teachers' content understanding, confidence and teaching self-efficacy beliefs (Fazio et al. 2020; Bleicher 2006; Balunuz et al. 2001; Cakiroglu and Boone 2002). This has a very strong impact on the teaching, including their future classroom activity plans and practises and their classroom management (Lumpe et al. 2011; Samuel 2017; Samuel and Ogunkola 2015).

The reasons for this trend are manifold but it may help to look at the method of teaching these subjects have been exposed to at all school levels. The most common method remains, indeed, the "traditional" one, characterised by lectures

---

A. Postiglione (✉)
Laboratori Nazionali di Frascati, INFN, Frascati, Italy
e-mail: adriana.postiglione@lnf.infn.it

I. De Angelis
Dipartimento di Matematica e Fisica, Università degli Studi Roma Tre, Roma, Italy
e-mail: ilaria.deangelis@uniroma3.it

I. De Angelis · E. Bernieri
Sezione di Roma Tre, INFN, Roma, Italy

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2023

J. Borg Marks and P. Galea (eds.), *Physics Teacher Education*,
Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-44312-1_11

during which students have an exclusively passive role and can rarely see the scientific method coming to life (Fazio et al. 2020; Jarrett 1999; Hawkins 1990). Thus, science becomes a sterile sequence of contents to be learned by heart and loses the experiential approach that represents its core. Unfortunately, this can also be true at university level for the primary education degree courses, where in some cases, in addition to the above aspects, students are also left with the difficult task of translating the disciplinary contents they are exposed to into concrete didactic activities for their pupils (Fazio et al. 2020; Aiello-Nicosia and Sperandeo-Mineo 2000).

In recent years, several research groups have worked to try and change this method of teaching (Fazio et al. 2020; Bleicher 2006; Jarrett 1999; Aiello-Nicosia and Sperandeo-Mineo 2000). It became clear that an effective approach to science requires an active involvement of students and an inquiry-based approach (Freeman et al. 2014; Prince 2004; Hake 1998), so that students can develop scientific skills rather than just accumulate knowledge. In fact, it is precisely this idea that inspired the Italian National guidelines on teaching (Ministero dell'Istruzione 2012) and the European recommendations for a renewed pedagogy for the future of Europe (Rocard 2007).

Aspiring teachers must thus be engaged in non-traditional activities, such as real laboratory activities where they can experiment hands-on or be involved in lessons aimed at building and strengthening their teaching method by sharing educational proposals and resources. Moreover, particular attention must be paid to giving them the message that an equipped laboratory is not necessary to carry out an experimental activity, but that instead numerous effective experimental proposals can be carried out with low-cost material, even in the normal classroom (Fazio et al. 2020; Comitato Tecnico Scientifico del progetto LS-OSA 2021; https://ls-osa.uniroma3.it/pages/posts/1).

In this context, at Roma Tre University we conducted a series of lessons for the Physics Education Course for the Primary Education Science Department, with the aim of improving students' confidence in dealing with experimental activities, while showing them how to use the scientific method to analyse physical phenomena. Due to the Covid-19 emergency, these lessons were held in online mode.

The paper is organised as follows: In Sect. 2, we focus on the structure of our proposal and the choices we made to build it. We describe the lessons we conducted in more detail. In Sect. 3 we discuss the feedback we received from the students and finally, in Sect. 4, we sum up our results and present our conclusions.

2 The Proposal

Our proposal had to be a part of a course that typically involves 300 students every year. Students are typically divided into three groups; moreover, our proposal had to be structured into four lessons, each lasting two hours. These lessons were to be held in the period March–April 2021, during the Covid-19 emergency. We thus had to consider both the need to carry out online activities and the high number of students involved.

Despite these unhelpful elements, we have tried to conceive and structure four lessons, making them as interactive as possible, with the aim of encouraging our students' confidence about physics teaching. We also wanted students to reflect on the scientific method, learn about educational activities that can be easily replicated in the classroom, put themselves to the test with simple but effective experiments and build a wealth of resources and tools to be used to design their laboratory activities autonomously. In order to achieve this, especially considering that all the lessons had to be held online and not face-to-face, we carefully selected experiments and proposals that could be easily followed and/or replicated by the students. Moreover, interactivity with students was favoured not only by the chat and the microphone, which could be used by participants at any time, but also by a series of closed-ended questions which students were asked to answer directly from their mobile phone. Specifically, students were challenged to answer those questions correctly *and* quickly to climb a ranking, which made the atmosphere playfully competitive. For this purpose, we used the platform *Kahoot!* (https://kahoot.com; Wang and Tahir 2020). In the following sections, we describe in more detail the lessons of the proposal.

2.1 First Lesson: Retracing the Scientific Method

The first lesson was focussed on the scientific method, as students were guided to retrace its steps with an inquiry approach: (1) Listen to a description of a phenomenon, reflect on it and answer a question about it; (2) Observe the phenomenon and take appropriate notes about it, up to being able to formulate a hypothesis about it; (3) Test the hypothesis and debate it with colleagues or mates to find a scientific explanation. The phenomena we presented were all reproducible using low-cost and everyday materials.

The following is an example of how a lesson was conducted:

The teacher asked: "*If I take two plastic bottles, one of which is empty and the other full of water and I drop them, which one will fall to the ground first?*" or "*What happens if I hang bolts of different masses onto a thread and make them oscillate? Would their speed be different?*". Before answering, the teacher encouraged each student to provide an answer to the question. To do this, he used the game *Kahoot!*, which makes it easier for even the most timid students to respond and take a stand without fear of being judged, since their answers remain anonymous. Only after getting the answers, the teacher performed the related experiment and commented on all the possible answers considering the experiment results, checking the hypothesis formulated by the students and finding a scientific explanation. We therefore tried to take advantage of Kahoot's gamification nature to stimulate students to actively participate in the lesson in an informal way, challenging them to give their best interpretation of the observed phenomenon.

The final part of the lesson was then dedicated to a didactic reflection on the lesson itself, with the aim of making students understand that they themselves could replicate this type of approach with their future pupils. To do this, the teacher retraced the steps that led him to design and implement the lesson and underlined its main features: the guided discussion about the experiments, the fact that he did not use an equipped laboratory or mathematical formulas, and the fact that participants' involvement and reflection was guaranteed even in online mode.

The main objective of this lesson was indeed to demonstrate that it is possible and easy to carry out an experiment even with a simple bottle of water or some bolts and to respond to pupils' curiosities through a practical activity.

2.2 Second Lesson: An Example of an Educational Activity

The second lesson was aimed at presenting an already structured practical educational activity, which preservice teachers could easily replicate with their pupils. The activity we used was focused on the relationship between the Earth and the Sun, on the seasons and time zones, specifically observing the way in which sunrays hit a specific point of the globe, both in terms of latitude (seasons) and longitude (time zones). The activity involved making use of easily available tools such as a common world globe, some paper clips, and toothpicks. The globe was used to reproduce the Earth's illumination in real time. Using the globe in this way, simulating the Earth's orientation in space, is often called *oriented globe* (Lanciano 2009; Postiglione and Angelis 2021). A *gnomon* (made by paper clips or toothpicks) placed on the oriented globe surface represents a person standing in a specific place on Earth. The shadow of the gnomon (as well as that of the real person standing on Earth) is directly linked to the position of the Sun in the sky, as seen by a person on Earth: that is, depending on whether this person observes the Sun towards the North, South, East or West and at what height to the horizon. Therefore, positioning the gnomons on the oriented globe allows for the investigation of time and season of different places on Earth, giving life to a practical and very effective activity, particularly suitable for primary education (Corbo and Scarpel 2009; Postiglione 2022).

To include this activity with the oriented globe in our online proposal, we used a video we pre-recorded simulating the in-person activity through a narrator who guides participants with step-by-step instructions.[1] During the lesson, the teacher showed the video in pieces, commented in depth on all the aspects treated, and, thanks to Kahoot gamification, stimulated students' participation by asking questions. It is worth noticing that, in this case, the questions proposed were designed to bring out and underline the most common misconceptions, such as those related to the meaning of the seasons or the tropics, making preservice teachers reflect on them. A more detailed analysis of this aspect can be found in Postiglione (2022).

---

[1] The video can be found at: https://www.youtube.com/watch?v=osM8paBQEGE.

Similarly to what was done in the first lesson, the last part of the second lesson was dedicated to a didactic reflection on the lesson itself. The way of how to bring the proposed activity specifically to the classroom was addressed: for example, by designing more than one lesson, each dedicated to one of the topics treated (the alternation of day and night, the changes in the position of the Sun in the sky during the year…) during which the use of the oriented globe is accompanied with other approaches like collective discussions, games, drawings and software. The possible usage of *Kahoot!* or the video was also underlined. Thus, the main objective of this lesson was to present an example of a complete teaching activity, including practical experiences and possible ways of presenting it in the classroom.

2.3 Third Lesson: Get Your Hands on Physics

If the previous lessons were intended to show educational approaches or activities that preservice teachers could use in the future, the third lesson wanted to give these students the opportunity to conduct the experiments themselves in real time. In fact, students were asked to carry out some simple physics experiments together with the teacher, following step by step instructions. Students were asked to prepare in advance some materials readily available at home (plastic containers, jars, paper clips, toothpicks, straws, rubber bands, a flashlight, and some milk) that would be necessary for the experiments.

All the experiments proposed dealt with some of the most common questions children ask adults: "*What is a rainbow?*" or "*Why is the sky blue?*" or "*Why does the water wet?*". The search for answers included experiments with water and light about topics such as the diffusion of light, the nature of colours and surface tension. During the realisation of all the experiments, students were guided in their activities with specific instructions and tips. Moreover, students asked questions on both practical and theoretical aspects and shared their satisfaction of being able to successfully carry out the experiment with the rest of the class.

As always, particular attention was paid to the analysis and reflections about the ways in which future teachers could bring the proposal into their classes. This lesson was thus aimed at addressing and trying to overcome the fear that students show in dealing with experimental activities on scientific topics and to strengthen the idea that an equipped laboratory is not necessarily needed to carry out practical activities.

2.4 Fourth Lesson: Building a Wealth of Resources and Tools

The last lesson of the course was intended to summarise and reflect on the previous lessons and to leave students with a wealth of additional resources and tools to autonomously use in their future teaching. Specifically, a series of freely accessible websites and platforms were proposed, from which students could get ideas on how to teach, based on experiments and activities that involve students.

For example, the Exploratorium website (https://www.exploratorium.edu; Oppenheimer 1972) was presented and discussed, providing an unmissable point of reference for the world of science teaching. *Science snacks* (https://www.exploratorium.edu/snacks) have provided the opportunity to reaffirm that practical activities can be carried out also in spaces other than the laboratory (such as the classroom, the school garden…) and that low-cost materials make it possible to create effective and fun activities that can make students 'touch' science with their own hands. The websites created by some scientific institutions and dedicated to teaching resources were also referred to. These included the European Space Agency (ESA) (www.esa.int/Education/Teachers_Corner/Primary_classroom_resources) and the Italian National Institute of Nuclear Physics (INFN) (https://web.infn.it/infn-kids/). In this case, the goal was twofold: indicating the didactic activities presented on these websites, but also making students aware of the scientific realities surrounding them. These can be used as a reference point for life-long learning.

This lesson also included the presentation of the activities that the Department of Mathematics and Physics of Roma Tre University proposes for schools (https://matematicafisica.uniroma3.it/terza-missione/per-la-scuola/). A list of books and other useful tools for teaching then concluded the session. Thus, this lesson helped students build a basic toolbox to carry out their future hands-on teaching activities.

2.5 Student Participation

The entire cycle of four lessons was followed by 275 students. At the end of each lesson, we administered an evaluation questionnaire with students. The first three questionnaires only concerned the related lesson, while the last questionnaire included both a part relating to the lesson and a part relating to the entire proposal. We received 272 answers to the first questionnaire, 271 answers to the second, 270 to the third and 270 to the fourth and last.

3 Feedback Received

In order to assess whether the proposed lessons managed to achieve our goal of encouraging students' confidence in dealing with scientific topics and laboratory activities, it is useful to look at the answers received on the evaluation questionnaires. The individual lessons were well received by the students, since on average, 99% of the students found them interesting (and over 60% *very interesting*). Moreover, the proposed activities turned out to be replicable and didactically valid, so much so that 99% of students stated that they plan to replicate them with their future pupils.

Similar reactions can be highlighted for the proposal in general, which was found to be overall interesting and useful by all students (100% of the total answers). When directly asked if they think the proposal will help them in their teaching and in proposing laboratory activities in their classroom, all students answered in the affirmative.

In addition to these positive answers, which were the result of closed-ended questions, it was worth analysing the comments that the vast majority of participants (about 90%) left at the end of the questionnaires, even if these were not mandatory. In fact, such a high percentage of free comments allows to draw a good picture of students' state of mind, summarised in the following qualitative analysis.

Many comments left by participants shed light on the impact the course has had on their confidence and teaching self-efficacy. Several students refer to have had, in the past, a feeling of fear and inadequacy when approaching science subjects but now state that they have overcome it thanks to our proposal. The following are some examples:

> Thank you because I was very afraid of attending this course…I changed my mind and I am even enjoying it very much!;
>
> Honestly, at first I was quite scared by the contents of this course, but I must say that I immediately had to change my mind.;
>
> I'm satisfied with the lesson, also because it is a subject far from my previous studies and at first it scared me.;
>
> It was an interesting lesson, which allowed me to overcome the 'fear' that very often we experience when we think about carrying out activities related to this subjects at school.;
>
> Before starting the lessons, I was afraid of not being in a position to fully understand the concepts, but I changed my mind.

Moreover, the lessons changed students' ideas on the role of the laboratory in physics teaching. Specifically, they claim that our proposal showed them the importance of using a laboratory approach with children:

> I learned that it is essential to make children approach science through doing and observing…;
> …I believe that it is very important to preserve and transmit this [proposal] orientation in teaching, to ensure that children gradually conquer the notions starting from the direct observation of natural phenomena…;
>
> These lessons proved useful to give me a more adequate understanding of the meaning of physics education, a laboratory education, based on the pupil, their starting knowledge, but above all their curiosity.

Students recognise—with surprise—that it is possible to propose laboratory activities with inexpensive everyday materials:

> the course was very useful, as it simply showed us that even with inexpensive materials it is possible to make the subject interesting.;
>
> It is fascinating to see how difficult concepts which one may think would require particular tools, are instead accessible to anyone.;
>
> Now I know that through a few simple materials various physical phenomena can be explained and children can become passionate about science.;

> I am very happy to see the closeness between what was explained in the laboratory activities and everyday life.

Students declare that they now feel confident enough to bring these kinds of activities in the classroom:

> Now I know how to successfully prepare a laboratory without being afraid of any possible 'risks' that might arise;
>
> I believe that this course is very useful and interesting and that at the end I will really know how to set up a basic lesson on physics in primary school, above all thanks to the ideas and experiments that have been proposed to us;
>
> I feel ready to replicate the experiments myself with my pupils.;
>
> I can't wait to experience all of this in the classroom and to see the faces and reactions of the children!

As regards the proposal structure, a very recurring theme is the strong appreciation for its inquiry-based and interactive approach which allowed students to "get their hands" on physics and thus discover its intrinsic beauty contrary to its presumed boredom and sterility:

> I was particularly interested in this course because I was also able to directly experience and therefore put my hands on physics. I think it was important to organise this kind of more practical lesson, during which we as students put ourselves to the test;
>
> I'm honest, I've always believed that physics was a planet so far away from mine. Yet I like this physics, it intrigues me, it stimulates me.;
>
> I must say that […] I have always seen physics as a difficult and boring discipline. The teachers, through the ideas provided during the course, made me see this discipline in a different light;
>
> I find these lessons very interesting, because they deal with subjects that I have always found difficult, discovering instead that I can, through small "experiments", understand otherwise complex theories and topics.;
>
> The clarity of the course […] was enlightening in explaining a matter that generally remains more static if there are no elements available to make it alive.;
>
> I appreciated that this proposal provided a practical and not just a theoretical study

Moreover, the interactivity guaranteed during the lessons thanks to the use of *Kahoot!* was also very appreciated:

> This course was very interesting and I really appreciated the use of Kahoot! to make it more fun and interactive.;
>
> …I particularly appreciated the way students were given the opportunity to actively interact during the lessons.;
>
> The fact that teachers offered us the game on Kahoot! helped me to maintain concentration and attention throughout the lesson.

Another often cited element was the choice not to leave, only to students, the difficult task of translating the disciplinary contents into concrete didactic activities, as it often happens, but instead to propose educational activities that can serve them as an example for their future teaching:

> This course has been one of the most interesting of my career, because it dealt with concrete examples of teaching. Usually, in fact, we study the subject, but how to teach it is almost never addressed;
>
> Activities to be proposed in our future classes are not always highlighted during courses, but today it was like that.;
>
> The hints and ideas provided during the lesson enriched our knowledge and our capability to apply them in the classroom.;
>
> I found several ideas that I can apply in primary school classes.

Finally, about the online nature of our proposal, the majority of students found the lessons effective, useful and engaging, despite the online mode:

> Despite the remote modality, it was not a boring laboratory, a theoretical laboratory, a simple lesson, but instead our collaboration was sought, we were encouraged "to do".;
>
> Although [the proposal] was done remotely, I think it has not lost its spirit, but on the contrary, it proved to be equally interesting and successful.;
>
> The teachers found a way to make us participate despite the distance, and contributed in a concrete way to the construction of our professional development;
>
> …unfortunately the course was held online, but despite this I feel I have enriched my cultural background).

Only in rare cases students explicitly reported suffering difficulties or problems related to the remote modality:

> I think that unfortunately, the remote modality greatly reduces interactivity compared to face-to-face work, together with all that experiential and practical component that a well-structured laboratory like this could offer us.;
>
> The only problem [of the course] was the distance, it would have been more fun and engaging if held in person;
>
> Although the topic was interesting, in my opinion the "remote" experiment did not yield what it could have done in person.

Despite this, some students appreciated our course so much that they considered it comparable or even preferable to other laboratory courses previously carried out even in person:

> It was one of the most interesting laboratory courses offered by our Degree Course;
>
> If only all the lab courses were so well organized!;
>
> These are some of the most useful laboratory lessons I have taken so far.;
>
> I had never participated in such an interesting and nice lab course.;
>
> From my University first year I have never done such a practical laboratory, and in my opinion this is a great lack for us future teachers.).

4 Discussion and Conclusions

In this paper, we presented a series of lessons we proposed for the Physics Education Course for the Primary Education Science Department at Roma Tre University, with the aim of encouraging students' confidence in dealing with physics topics and experimental activities. Specifically, we created four online lessons aimed at making students see the scientific method come to life, learn about ready-made educational activities that can be easily replicated, put their hands on physics with simple but effective experiments and build a wealth of educational resources and tools. Despite the online mode and the high number of students involved (275 divided into 3 groups), we managed to guarantee interactivity with the students during the lessons, also through fun quizzes to be answered anonymously using *Kahoot!*.

Our proposal identifies four steps (focus on scientific method, example of an already optimised activity, chance to get hands-on physics, wealth of resources) that seem to encourage a laboratory approach in physics teaching. We hope that these steps, which in our case converge to our four lessons, can represent the backbone for other proposals concerning science education of future primary teachers, which can also treat topics different from the ones we chose.

From the feedback we received from our students in terms of responses and comments left to the evaluation questionnaires administered at the end of the individual lessons and of the entire proposal, some elements indeed clearly emerge. The feedback has shown that our work can indeed contribute to the collective effort of improving primary teachers' content understanding, confidence and teaching self-efficacy beliefs regarding science.

The first element concerns the sense of fear and inadequacy students felt before approaching the proposal, which translated into a low teaching self-efficacy belief. Specifically, students believed that they were incapable of understanding the contents the course would present, because they were too difficult or too far from their preparation, so much so that they thought the course would be useless for them (although mandatory).

Another element that emerges is the role of laboratory activities in science teaching, which students completely underestimated before the lessons. After attending the course, however, students identified their role of engaging and entertaining their future pupils using the experimental approach. This awareness arises also from the fact that the proposal allows them to discover that laboratory activities do not necessarily require an equipped room or complicated materials, but that instead they can be carried out with simplicity, with everyday materials.

Another recurring theme we found among students' responses is the sense of change they have in their perception of science as a discipline, which we hope can be poured out in an indirect way into their future teaching. Starting from the sad idea of a boring, static, and sterile science, students discovered instead the wonder and excitement of discovery. This was due to the possibility offered to them by the course to understand the scientific method in a deeper way, and to put themselves to test with simple but effective experimental activities. An important role in this context was played by the strong interaction guaranteed during the lessons, also through the usage of *Kahoot!*, which encouraged the participation also of the most shy students.

A peculiar aspect of our proposal is that it was held online. Although we believe that the experiments we proposed would have worked better in person, only a few students explicitly reported to have suffered the remote modality. In fact, most of them consider the proposal effective and useful, so much so that some of them claim that our course is comparable or preferable with respect to other laboratory courses attended so far, even in person. Moreover, this seems to indicate that the effort we made in selecting appropriate experiments paid off. Of course, we are aware that only a face-to-face proposal could allow to widen the pool of experiments that can be proposed to students in an effective way.

Finally, a relevant aspect underlined by the participants concerns the fact that during the proposal many examples of already built and optimised didactic activities have been provided. In this way, students not only better understand the topics covered, but also feel supported in the difficult task of translating scientific contents into real lessons, which improves their confidence and self-efficacy.

All these issues, of course, are vast and articulated, and we are aware that our proposal can only represent a small contribution, which however goes in the right direction. A strong improvement to our proposal, for example, would consist in carrying out also these activities in person, to reinforce students' idea that science teaching must include two very important characteristics: the experiential approach and the sharing of ideas. Furthermore, it must be said that carrying out the lessons in person would also allow us to follow the preservice teachers' testing the proposed activities with their pupils.

References

Aiello-Nicosia ML, Sperandeo-Mineo RM (2000) Int J Sci Educ 22:1085Y1097

Balunuz M, Jarrett OS, Bulunuz N (2001) Annual meeting of the National Association for Research of Science Teaching, St Louis, MO

Bleicher R (2006) J Sci Teach Educ 17:2

Cakiroglu J, Boone WJ (2002) J Elem Sci Educ 14:1–14

Comitato Tecnico Scientifico del progetto LS-OSA (2021) Fare laboratorio: guida alla didattica esperienziale. Accademia delle Scienze di Torino

Corbo L, Scarpel N (2009) Sole e ombre sul mappamondo da...terrestri, abstract from the book "Astronomia in rete", Edizioni MIUR http://www.globolocal.net/download/6sd.pdf

Exploratorium website: https://www.exploratorium.edu

Fazio C, Di Paola B, Battaglia OR (2020) Int Electron J Elem Educ 13:89–105

Freeman S et al (2014) Proc Natl Acad Sci USA 111:8410–8415

Hake R (1998) Am J Phys 66:64–74

Hawkins D (1990) Defining and bridging the gap. In: Duckworth E, Easley J, Hawkins D, Henriques A (eds) Science education: a minds-on approach for the elementary years. Lawrence Erlbaum, Hillsdale, NJ, pp 97–139

Jarrett OS (1999) J Elem Sci Educ 11:49–59

Kahoot! A game-based learning platform: https://kahoot.com

Lanciano N (2009) Strumenti per i giardini del cielo. Edizioni Junior (abstract from the book: http://www.globolocal.net/download/mappamondo%20parallelo.pdf)

List of the initiatives for schools proposed by the Department of Mathematics and Physics of Roma Tre University: https://matematicafisica.uniroma3.it/terza-missione/per-la-scuola/

LS-OSA project. https://ls-osa.uniroma3.it/pages/posts/1

Lumpe A, Czerniak C, Haney J, Beltyukova S (2011) Int J Sci Educ 34(2):153–166

Ministero dell'Istruzione, dell'Università e della Ricerca, Indicazioni nazionali per il curricolo della scuola dell'infanzia e del primo ciclo d'istruzione (2012) http://www.indicazioninazionali.it/wp-content/uploads/2018/08/decreto-ministeriale-254-del-16-novembre-2012-indicazioni-nazionali-curricolo-scuola-infanzia-e-primo-ciclo.pdf; Indicazioni nazionali per i percorsi liceali https://www.gazzettaufficiale.it/gunewsletter/dettaglio.jsp?service=1&datagu=2010-12-14&task=dettaglio&numgu=291&redaz=010G0232&tmstp=1292405356450

Oppenheimer F (1972) Am J Phys 40:978

Postiglione A (2022) Il Nuovo Cimento 45C:91

Postiglione A, De Angelis I (2021) EduLearn2021 proceedings. ISBN: 978-84-09-31267-2

Primary teaching resources from ESA website: www.esa.int/Education/Teachers_Corner/Primary_classroom_resources

Primary teaching resources from INFN website: https://web.infn.it/infn-kids/

Prince M (2004) J Eng Educ 93:223–231

Rocard M et al (2007) Science education now: a renewed pedagogy for the future of Europe. European Commission. www.eesc.europa.eu/sites/default/files/resources/docs/rapportrocardfinal.pdf

Samuel D 2017 Elementary school teachers' science teaching efficacy beliefs as predictors of their inquiry-based practices in science instruction. In: Hordatt C (eds) 60th Yearbook of teacher education, international council on education for teaching, school of education. Gentles Faculty of Humanities and Education, The University of the West Indies, pp 293–307

Samuel DF, Ogunkola BJ (2015) Int J Elem Educ 4(6):101–112

Science Snacks from Exploratorium: https://www.exploratorium.edu/snacks

Wang AI, Tahir R (2020) Comput Educ 149:103818

Physics for Primary School Teachers in Italy: Comparative Analysis in a Dedicated Survey

Maria Luisa Chiofalo, Olindo Corradini, Ilaria De Angelis, Lidia Falomo Bernarduzzi, Massimiliano Malgieri, Claudio Sutrini, Marco A. L. Giliberti, Josette Immè, Marisa Michelini, Giovanni Organtini, Stefania Pagliara, Maura Pavesi, Carlo Sabbarese, Francesco Salamida, and Samuele Straulino

Abstract In Italy, a five-year university course "Scienze della formazione primaria", which can be translated as Primary Education Degree Course (henceforth PEDC), is dedicated to train the future teachers of kindergarten and primary school (age range 3–11). The Italian project PLS-Physics ("Piano Lauree Scientifiche"), financed by the government and coordinated by J. Immè, has among its objectives the improvement

---

M. L. Chiofalo
Dipartimento Di Fisica, Università Di Pisa, Largo Bruno Pontecorvo 3, 56127 Pisa, Italy

O. Corradini
Dipartimento Di Scienze Fisiche, Informatiche E Matematiche, Università Degli Studi Di Modena E Reggio Emilia, Via Campi 213/A, 41125 Modena, Italy

I. De Angelis
Dipartimento Di Matematica E Fisica, Università Degli Studi Roma Tre, Via Della Vasca Navale 84, 00146 Roma, Italy

L. Falomo Bernarduzzi · M. Malgieri · C. Sutrini
Dipartimento Di Fisica, Università Di Pavia, Via Bassi 6, 27100 Pavia, Italy

M. A. L. Giliberti
Dipartimento Di Fisica "Aldo Pontremoli", Università Degli Studi Di Milano, Via Celoria 16, 20133 Milano, Italy

J. Immè
Dipartimento Di Fisica E Astronomia "Ettore Majorana", Università Di Catania, Via S. Sofia, 64 I-95123 Catania, Italy

M. Michelini
Dipartimento Di Scienze Matematiche Informatiche E Fisiche, Università Di Udine, Via Delle Scienze 206, 33100 Udine, Italy

G. Organtini
Dipartimento Di Fisica, Sapienza Università di Roma, Piazzale Aldo Moro, 2, 00185 Roma, Italy

S. Pagliara
Dipartimento Di Matematica E Fisica, Università Cattolica del Sacro Cuore, Via Garzetta 48, 25123 Brescia, Italy

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2023
J. Borg Marks and P. Galea (eds.), *Physics Teacher Education*,
Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-44312-1_12

of school-university cooperation, through a pre- and in-service teacher education. In this context, a group composed of PLS members (named PLS group 6, coordinated by M. Michelini) organized a national survey to gather information about the physics courses for PEDC in all the Italian universities. A picture of a living community that has chosen to confront and improve together has emerged. The aim of this study is to monitor the status of the art concerning the initial training of kindergarten and primary school teachers in Italy, as a first step for the creation of shared formative actions, also in a dialogue with the national government. The relation between teaching practice and physics education research has also been investigated.

1 Introduction

A quality training of kindergarten and primary school teachers, especially in the scientific field, is crucial for the future of each country.

In Italy, a specific legislation dating back to the late 1990s describes, in some detail, subjects and topics of the Primary Education Degree Course (henceforth PEDC), whose aim is preparing teachers of kindergarten and primary school. “Didactics of Physics with Laboratory” is one of the subjects required by the Italian law within the PEDC.

Experiences gained in this field during the last 20 years contain really interesting aspects that deserve to be preserved and shared. Physics Education Research plays a significant role in the Didactics of Physics course for PEDC: in the last decades a deep research on teaching in the early school age has been carried out, also for science (examples can be found in Bruner (1969), Arons 1979; Shulman 1986; Kitcher 1993; Michelini 2002; 2004; Duschl 2008; Park and Oliver 2008; Michelini et al. 2015; Tombolato 2020), and these contributions are valuable for this kind of teaching. Too often, basic science teaching is still linked mainly to textbooks. Many teachers spend a lot of time explaining concepts and only a few actively involve children in conducting experiments or explorations. Already in 1986, Shulman’s theory on

---

M. Pavesi
Dipartimento Di Scienze Matematiche, Fisiche E Informatiche, Università Di Parma, Parco Area Delle Scienze, 7/A, 43124 Parma, Italy

C. Sabbarese
Dipartimento Di Matematica E Fisica, Università Della Campania, Viale Lincoln 5, 81100 Caserta, Italy

F. Salamida
Dipartimento Di Scienze Fisiche E Chimiche, Università Dell’Aquila, Via Vetoio, 42, 67100 Coppito, Italy

S. Straulino (✉)
Dipartimento Di Fisica E Astronomia, Università Degli Studi Di Firenze, Via G. Sansone 1, 50019 Sesto Fiorentino, Italy
e-mail: samuele.straulino@unifi.it

Pedagogical Content Knowledge (PCK) (Shulman 1986) required that the formative process for the teachers should include an integration of pedagogical knowledge, disciplinary knowledge and specific knowledge of teaching materials. The Italian National Guidelines (Ministero dell'Istruzione 2012) for kindergarten and primary school provide a reference text for the topics to be addressed and for the suggested methodologies, and aspects to be considered also in the drafting of Physics Education programs for PEDC.

2 The Reasons for a Survey and Its Structure

The working group PLS-6 conducted many internal meetings and decided to organize a national survey on physics teaching at PEDC. The main reason was the urgency to know something more on these courses throughout the country; we considered the importance of identifying the actions which could be useful to facilitate coordination among different universities and to improve the quality of didactics, favoring the exchange of disciplinary didactic research. A joint effort of the Italian universities in the field of primary scientific education is really important, also for planning future legislative actions together with the government.

The survey we submitted to our colleagues is composed of 25 items, divided into:

(*a*) general information and (*b*) specific questions, the latter requiring more detailed answers (see Table 1). For (*a*) we had 16 items, concerning covered topics, adopted methods, number of students, characteristics of the laboratory and dissertations. The remaining 9 items in part (*b*) focused on the reasons for the selection of the program, the measures adopted to take into account both school levels (kindergarten and primary school) for which the PEDC course prepares students, the role of phenomenological and formal aspects, the relevance of problems and exercises, the role of the laboratory and the relations with the internship tutors, the possibility for students to prepare and implement educational projects, the difficulties faced by university students taking physics and the difficulties faced by the university teachers in the way they teach.

Thirty university teachers answered the survey, covering all the Italian universities delivering PEDC courses. This represents a complete picture of physics courses for the training of primary school teachers in Italy.

3 Results of the Survey

Here we briefly discuss the replies, making reference to the item number indicated in Table 1.

Generally, 8 credits are assigned to the physics course, for a total of 48–64 h of lecture **(ITEM 3)**.

Table 1 The survey addressed to university teachers of physics at PEDC. Questions 1–16 require short replies, while 17—25 are designed for longer and more reasoned answers

PLEASE ANSWER TO ITEMS 1—25, with reference to your own course	
1	Name of the University
2	E-mail address of the university teacher
3	Hours per credit, except for the laboratory
4	Topics covered in the program: please select (a list of topics is given)
5	Time dedicated in your course specifically to "physics education"
6	Average number of students per year enrolled in the PEDC degree course
7	Average number of students attending physics lectures (laboratory attendance was mandatory)
8	Type of final assessment
9	Hours per credit, for the laboratory
10	Methods adopted in the laboratory
11	Maximum number of students in each laboratory
12	Obligation to attend the laboratory
13	Name of the university teacher, for the laboratory
14	Implementation of laboratory activities
15	Assessment methods, for the laboratory
16	Theses already assigned in physics education
17	Criteria which determined the choice of the topics
18	Role and weight in the course of physics contents and didactic aspects
19	How both school levels (kindergarten and primary school) are taken into account
20	Role and weight of phenomenological aspects and formal ones
21	Role and weight of exercises and problems
22	Relation between the course, the laboratory and the trainership
23	Role of didactic projects made by students
24	Major problems faced by the teacher of this course
25	Major problems faced by the students of this course

The topics covered in the programs **(ITEM 4)** have been compared with those mentioned in the Italian law DM 249 (2010), which are:

- Measurements and Units (included in the 82% of the programs)
- Density and Archimedes' principle (71%)
- Atomic composition of materials (32%)
- Elements of mechanics, celestial mechanics and astronomy (57%)
- Elements of electrostatics and electrical circuits (64%)
- Heat and temperature (86%)
- Phenomenology of thermodynamics (61%)
- Sound (46%)

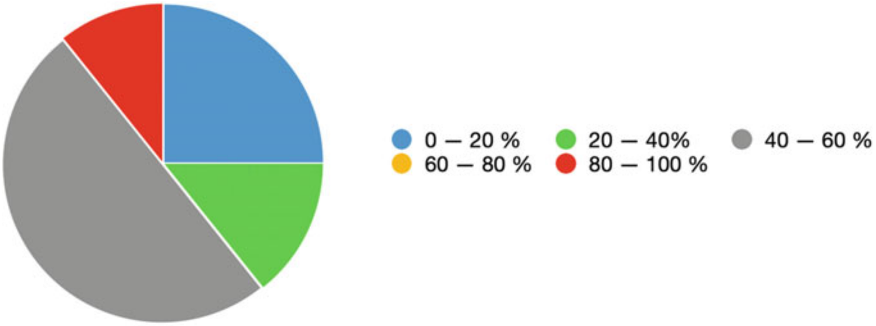


Fig. 1 This pie chart reports the percentage of didactics aspects within each physics course, that is the time dedicated to discuss how to explain physics in the classroom. About 60% of the university teachers (gray and red sectors in the chart) reserve 40% of time or more for this kind of education

Some university teachers add other topics such as momentum, work, energy, renewable energy sources, optics and history of physics.

The "didactic share" inside the course **(ITEM 5)** is very important in the physics teaching for PEDC, including the discussion on the results coming from the Physics Education Research. The relevance of the didactic part, communicated by the university teachers, is reported in the pie chart (see Fig. 1).

The number of enrolled students, which is rather different throughout the Italian universities, ranges from 50 to 300 students/year **(ITEM 6)**. Before the pandemic, the average number of class participants in the physics lectures was around 50% **(ITEM 7)**; for the laboratory, attendance is mandatory.

Concerning the type of final assessment **(ITEM 8)**, assuming that in some cases more than one type can be chosen, the majority of university teachers require the preparation of a report to be discussed during the examination (77%) or an oral examination (62%); less frequently we find a written examination (with open or closed questions) or the preparation of an artifact.

For the laboratory, 1 CFU (one university formative credit) corresponds everywhere to 12 h **(ITEM 9)**. The two mainly adopted typologies **(ITEM 10)** are "low cost materials" (74%) and preparation of a didactic project for the school (59%) (more than one type being possible in the choice). Classes are usually rather small (20–30 students) and participants are divided in small groups to carry out the activity **(ITEM 11)**. Attendance to the laboratory activities is usually mandatory **(ITEM 12)** and often the lecturer is the same university teacher **(ITEM 13)** who also takes care of the implementation of the activities **(ITEM 14)**. In terms of the laboratory assessment **(ITEM 15)**, there is mainly a written report to be discussed, both as individual work and in the small group, or a presentation to prepare.

In some cases, it may happen that students choose to tackle a final dissertation in physics education **(ITEM 16).** The most recurrent topic is the creation of detailed projects for kindergarten or primary school. Less frequently, comparative studies on science textbooks for children are undertaken.

Some general questions were asked in the second part of the survey. The answers received were not very similar and rather reflected local specificities. We report here a summary of the most recurrent and significant responses.

Regarding the reasons for the selection of the course topics by the university teachers **(ITEM 17)**, these were the most varied. For example, the following are mentioned: refreshing the knowledge of physics; giving the future teachers the ability to answer questions about the everyday life phenomena; enabling them to design, implement and analyze small experiments with poor materials, with a special focus on the ability to analyze any failures; selecting some topics generally present in the primary school's textbooks. The reference to the Italian law in this context and the relation with the physics education research are also fundamental.

As anticipated, the course generally contains both a disciplinary part, considered unavoidable due to the scarce basic knowledge in a significant share of students, and a discussion on many didactic aspects **(ITEM 18)**. Some university teachers note that in a course like this one, the disciplinary part is steeped in didactics and a clear separation of the two parts is not possible. The attention for the specific role of the kindergarten **(ITEM 19)** is present in almost all university teachers, although some of them struggle to find a way to transfer disciplinary content to pupils of this level of education.

Generally, the discussion with university students begins from the phenomenological aspects leading to a modeling one, but even in this case the two aspects are not rigidly separated **(ITEM 20)**. Regarding problems and exercises **(ITEM 21)**, many university teachers make only use of a few very simple ones, as tools for verifying the acquired knowledge.

In some universities, a collaboration has developed with the internship tutors for the laboratory part **(ITEM 22).** Tutors help students in their didactic projects concerning the choice of contents and methodologies. In some cases, the tutors also collaborate for dissertations.

Students are progressively guided to structure a learning path on physics topics **(ITEM 23)** taking into account the age of the children and their foreknowledge, the National Guidelines, the most important thematic nuclei for kindergarten and primary school and the most effective strategies for teaching science.

The university teachers report several problems with this course **(ITEM 24)** namely: the poor basic preparation of the students and their lack of confidence towards being able to improve significantly; the difficulty of managing the formal aspects of physics, often entrusted to mnemonic procedures; low attendance at lectures, due to the fact that many of the students already have a job; the scarcity of available textbooks and other educational material; the small share of time dedicated to the laboratory.

On the other hand, even students interviewed by the university teachers report some difficulties with the physics course **(ITEM 25)**: mainly the lack of adequate basic preparation in science and the disproportionate workload compared to other subjects.

4 A National Meeting on Primary Scientific Education

The survey was later exploited to organize a National Meeting on the Physics courses for primary school teachers, where these problems could be extensively discussed. The meeting was held online on February 12, 2021. It was composed of plenary sessions, where significant case studies have been presented and discussion tables, focused on the main items of the survey. The results of the meeting are reported in a dedicated issue of the Giornale di Fisica (2022), edited by the Italian Society of Physics ([Società Italiana di Fisica (SIF) http://www.sif.it]).

After a long and in-depth transversal discussion, participants came to agree that the possible multiplicity of topics to be addressed should be presented with a terminology that focuses on natural phenomena in a broad sense, to arrive gradually to discuss aspects increasingly framed as disciplinary. So, for example, university teachers will not talk about optics, but about light, colors and vision; not about mechanics, but about forces, movement and energy; not about thermodynamics, but about heat and temperature, states and thermal processes and so on. Other topics of interest for such kind of future teachers are electricity and magnetism, sound, mechanical waves, strings and springs and oscillations. The sky and stars are also very important, but also matter and materials, fluids and buoyancy. There is still a question about the opportunity to introduce among the topics essential elements of quantum physics. The structure of the discipline and the way it is taught must be different. For example, the formation of images, the sensations that light and colors can generate when observed, for example at sunset, the emotions involved and the way they are expressed are also relevant when talking about light. At kindergarten and primary school, the approach to science is multidisciplinary. The just mentioned topics do not form in any way an ordered list, as girls and boys do not yet have a structured disciplinary conception and the first approach to the sciences will therefore be dictated by the perception of nature's primary "forces", such as, for example, rain, wind, clouds and sun. From the didactic point of view, the opinions of common sense can be seen as an opportunity to propose a reworking on which to build disciplinary thinking, rather than erroneous ideas to refute because in conflict with disciplinary thinking.

During the meeting, the variety of contents, proposals and solutions for the physics course at PEDC emerged; the approach is still not organic and this suggests that the creation of further opportunities for meeting and discussion is fundamental. On the other hand, we did find, in all the Italian universities, attention to the didactic aspects, special care to the educational outcomes and liveliness of the teaching community.

5 Conclusions

The initial training in science of primary school teachers is a crucial task assigned to the University by the European Council and the Italian Ministry, in order to promote the development of the scientific culture in our country. The institutional teachings of Didactics of Physics and Laboratory in the PEDC contribute to this task (Michelini 2022).

We have identified the opportunity to discuss the great challenge faced in these courses in the last 20 years and developed a survey to collect tools, methods and contents of such courses. The preparation of the survey was shared in every detail, during a series of meetings of the PLS-G6 group (which the authors of this work contribute to), devoted to the planning of actions and activities aimed at training and professional development of teachers.

The identified items concerned: (1) the choices adopted regarding the number and the type of topics, the role of disciplinary contents and didactic aspects with relative weights for each topic, possible differentiation for kindergarten and primary school, attention to the vertical curriculum, role and weight of phenomenological and formal aspects, exercises and problems, relations with laboratory and internship, relations with other courses, practical and located activities with children, modalities and role of didactic projects by the students; (2) methods concerning group activities and related role, type of assessment; (3) characteristics and role of the laboratory: average number of people attending each laboratory, obligation to attend the laboratory, relations with the Physics course; (4) focus on the laboratory, in particular the relevance of carrying out educational experiments or experiments suitable for primary school, planning of didactic projects, planning of single didactic activities or assessment of the laboratory: modalities and formalities required; (5) characteristics of the assigned dissertations. The analysis of the data coming from the survey produced a first comparison, especially in terms of content. However, significant differences emerged in terms of approaches and focus, including mainly: discussion of didactic projects from research literature, analysis of concepts from a historical point of view, storytelling and integration with the disciplines of the humanities area and experimental explorations.

The survey has provided useful information on the organizational aspects of the courses. This is relevant to the work of the PLS-G6 group, also aimed at conceiving proposals for effective changes in the training system, which may benefit from the best experiences spread over the national territory, in the spirit of favoring the setting of a uniform standard. We have also learned that something like 2/3 of the interviewees dedicates more than 40% to the didactic aspects and that—even though the courses include both disciplinary and didactic aspects—it is often considered hard to separate them. The survey has produced a list of reasons for these difficulties, so far reported by the university teachers, which can be summarized as poor competences in formal aspects often left to mnemonic procedures, short time dedicated to laboratory work, and poor quality and quantity of dedicated textbooks and educational material. Also in the light of the considerations which emerged in the focus-group discussion at the National Meeting (reported in Sect. 4), these outcomes evidently support the motivations of the PLS-G6 working group: deep reflections are required on how physics is taught from kindergarten to the high school, before entering the PEDC. Previous gaps in mathematics and scientific education may hardly be recovered in the short time typical of a university course. Rather, a substantial change in the training and professional development programs for physics teachers at all levels of education is required.

References

Arons AB (1979) Some thoughts on reasoning capacities implicitly expected of college students. In Lochhead J, Clement J (eds) Cognitive process instruction, Franklin I. Press, Philadelphia

Bruner J (1969) Eye, hand and mind. In Elkind D, Flavell JH (eds.), Studies in cognitive development: essays in honor of Jean Piaget, Oxford U. Press, New York

Duschl R (2008) Science education in three-part harmony: Balancing conceptual, epistemic and social learning goals. Rev Res Educ 32(1):268–291

Immè J, Michelini M eds (2022) Quale didattica della fisica per formare gli insegnanti di scuola primaria, GdF, LXIII, Supplemento PLS-Fisica-FIP. [https://doi.org/10.1393/gdf/i2022-10468-2]. https://www.sif.it/riviste/sif/gdf/econtents/2022/063/s02

Kitcher P (1993) The advancement of science: science without legend, objectivity without illusions Oxford U. Press, New York

Michelini M (2002) Innovazione nella didattica universitaria per la formazione in fisica dei futuri insegnanti elementari e supporto del web *Formare* 16 Erickson

Michelini M (ed) (2004) Quality Development in Teacher Education and Training

Michelini M (2022) Research-based physics education of prospective primary teachers. G Fis 63(s02):1–27

Michelini M, Santi L, Stefanel A (2015) La formazione degli insegnanti in fisica come sfida di ricerca: problematiche, modelli, pratiche. Italian J Educ Res 14:191–207

Ministero dell'Istruzione, dell'Università e della Ricerca, Indicazioni nazionali, Roma (2012) (in Italian) https://www.miur.gov.it/documents/20182/51310/DM+254_2012.pdf

Park S, Oliver J (2008) Revisiting the conceptualization of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals *Res.* Sci Educ 38:261

Shulman LS (1986) Those who understand: knowledge growth in teaching. Educ Res 15:4

Società Italiana di Fisica (SIF) http://www.sif.it

Tombolato M (2020) La conoscenza della conoscenza scientifica. Problemi didattici Franco Angeli, Milano

COSID-20: Design and Testing of a Home-Kit for Physics Laboratory at a Distance with Future Teachers

Tommaso Rosi, Giuliano Zendri, Eugenio Tufino, Stefano Toffaletti, Stefano Oss, and Pasquale Onorato

Abstract Real experiments play an essential role in science education and in physics teachers' training. In the context of distance learning, one of the main challenges that educators must face is to not renounce to propose real experiments that require students to perform a rigorous data analysis. In the context of a project named COSID-20 (COllaborazioni per le Scienze In laboratorio Didattico-2020), we designed and tested a personalised home-kit that was sent to students of a Physics Education course. The kit is suitable for the contents of a laboratory-based course aimed at future physics teachers and designed to meet the general laboratory learning goals. The kit has been used by 18 student teachers in 2020 and 17 in 2021 and was also tested with 50 high-school students in 2021. Teaching material has been created that can supplement the teachers in carrying out some activities.

1 Introduction

School and university teaching, as well as teacher training, have been drastically affected by the Covid-19 pandemic. In 2020 the global education system led to a precipitous shift to distance learning (DL) and the social distancing measures have required Universities to promptly adapt to distance education methods, an adjustment which is particularly difficult for science laboratory courses (Fox et al. 2020, 2021). Because these are classes where teamwork and hands-on experiences are important and rely on the class being held in person, the design of physics laboratories in the event of a pandemic is very important (Moosvi et al. 2019; Howard and Meeting 2021; Campari 2021; Zvacek et al. 2019; Nancheva and Stoyanov 2005; Lucisano 2020). As a result, the community of lab educators had to devise and implement innovative and imaginative strategies to quickly migrate their courses to a remote

---

T. Rosi (✉) · E. Tufino · S. Toffaletti · S. Oss · P. Onorato
Department of Physics, University of Trento, Via Sommarive 14, 38123 Povo, Trento, Italy
e-mail: tommaso.rosi@unitn.it

G. Zendri
Level Up srl, Via Generale Giacomo Medici 4/1, 38123 Trento, Trento, Italy

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2023
J. Borg Marks and P. Galea (eds.), *Physics Teacher Education*,
Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-44312-1_13

format while maintaining their learning objectives. A crucial challenge has been to offer students a laboratory experience, authentic and meaningful, possibly collective (through organising group experiences using, for example, Zoom Workrooms in which multiple students could work on the same experiment), requiring rigorous data analysis and ensuring an active learning environment. Thus, we ask this main research question: Can a hands-on physics lab course be delivered effectively as a distance lab through the use of a Home-Kit? (Moosvi et al. 2019).

2 The COSID-20 Project

The COSID-20 project was created with the primary objective of increasing the resilience of universities in the face of emergencies such as the pandemic situation, especially with reference to courses based on laboratory activities. The project benefited from the participation of professors and researchers from different scientific areas.

COSID-20 involved many different activities, one of which is the presented project. In this context, we designed and tested a Home-Kit that has been used by 35 undergraduate students and 50 secondary school students. Our experience during the course and the findings from the questionnaire administered with student teachers at the end of the courses are reported here.

3 The Home Kit

In the early phase of the pandemic, in order to offer hands-on laboratory work at distance, we have been using different tools and methodologies that are well-suited for teaching at a distance: Remote Controlled Laboratories, Prerecorded Online Experiments (Virtual Remote Lab), Simulators and Simulations and household equipment (Kitchen Physics). Only these resources could help us address the problem of offering hands-on labs in a distance course. From the experience of this first year of pandemic, we designed and assembled our Home Kit, which has been used since September 2020.

For introductory science courses, the use of Home-Kits is an appropriate and viable instructional strategy (Fox et al. 2020, 2021; Moosvi et al. 2019; Howard and Meeting 2021). First, we used the kits in a Physics Education Laboratory course that mainly targets students who are interested in becoming middle and high-school teachers in mathematics and physics. We provided one kit to each student so that she/he could execute laboratory activities during distance learning, while collaborating with other students via video-conferencing.

In this work, we discuss our observations and findings about the use of the Home-Kit by students. As in Howard and Meeting (2021) the experiments were designed to match the existing onsite laboratory experiment learning goals and the general laboratory course learning goals.

4 The Content of the Kit

A design choice was made regarding the distance learning version. This was to keep the same content and try to perform the same experiments. With this decision in mind, the Kit has been designed, consisting of a list of materials that had to be bought and put together in two boxes, easy to handle and transport.

Because students must work without being supervised in person, the kits must be safe and must be designed in such a way that students can use it to perform experiments on their own.

The experiments that students carried out at home using the Kit covered a wide range of topics: from classical mechanics (Hooke law, Galileo' study on projectile motion) to thermal phenomena (specific heat, Newton's cooling law, thermal equilibrium), from electric circuits (Ohm's law, RC, LED characteristics) to geometrical and wave optics (Snell law, Beer Lambert Law, measurements with a diffraction grating, wavelength measurements), measurements of spectral transmittance up to Modern Physics (Measurements of Stefan-Boltzmann, Measurement of Planck constant with LED) (Zvacek et al. 2019; Nancheva and Stoyanov 2005).

The items that were finally inserted in the Kit can be seen in Fig. 1, while the entire list can be found in Table 1. In the latter, we also added references to the experiments that the items have been used in. Apart from the equipment contained in the Kit, students often had to use their mobile phones as a Pocket Lab (Sukariasih et al. 2019) and were occasionally asked to add other items for specific experiments (sheets of white paper, black cardboard, black adhesive tape, supports, metal pots/containers).

In Figs. 2 and 3, two examples of experimental apparatus prepared by the students are presented to the reader. As it can be seen from the list in Table 1, many items have been used in more than one experiment, and can potentially be used in many more, thus making this Kit very flexible and easy to prove itself as a valuable investment in the long term, which can even be used in the case of a come back to a complete in-campus course.

5 Results

A questionnaire, with answers given in a Likert scale from 1 to 5, was administered at the end of the semester, with the aim of evaluating the effectiveness of the distance learning labs. The experiences from the perspective of 35 undergraduate students

Fig. 1 The items of the Home-Kit

were analysed. A part of the questionnaire was devoted to exploring if the learning goals of the course had been met. Table 2 shows a list of 5 Learning Goals and the related questions In the same table, the results from two questions about the perceived difficulty of the course and the perceived effectiveness have also been included.

In Table 2, average scores are reported for 2 groups of students: the students who used our Home Kit and the students at Oglethorpe University who used the Kit designed by Howard and Meier (Moosvi et al. 2019). The largest difference in the results refers to the difficulties of the students in using the Home Kit instead of performing the experiments in the laboratory (Question 1). The students felt much more confident in using our Kit: this can be due to various reasons, such as the differences between the Kits, the time the students had available to become familiar with this methodology, the overall number of experiments performed, the previous experiences of the students….

In the questionnaire, the students also had to answer some questions regarding their attitudes towards the use of the kits and what they felt they had learned because of having them, as compared to the use of other methodologies such as the use of pure simulations or virtual/remote labs. We were interested in probing students' evaluation about their comprehension of a phenomenon thanks to the proposed activities (Effectiveness) and about their personal interest during the activities (Engagement). To do this, a list of activities students had used during the course was listed in the questionnaire, and for each item, students were asked to: (1) Rate their experience in terms of *effectiveness* and (2) Rate their experience in terms of *enjoyment*. The

Table 1 Summary table showing the components of the Home Kit provided to the students, the list of experiments that have been performed using the Kit and the additional materials that the students must make available on their own to perform certain experiments

Components of the Home Kit	Experiments in which they are used
2 Cables with crocodiles 12 Electrical cables 12 V bulb 2 Digital multimeters Universal power supply Power adapter Mini breadboard 9 Resistors	Experiment on the Stefan-Boltzmann law Experiment on Ohm's law
Digital scale 2 Transparent glasses	Beer's law experiment (concentration of the medium)
Filters (red, green and blue) Torch Food colouring	Beer's law experiment (concentration of the medium) Experiment on Snell's law and other light phenomena
2 Clear plastic containers	Experiment on Snell's law and other light phenomena
25 W incandescent bulb Table lamp	Beer's law experiment (medium thickness) Experiment with lamp and plates
Polystyrene support 1 Black washer 1 White washer	Experiment with lamp and plates
2 Food thermometers	Experiment with lamp and plates Experiment on Newton's law of cooling Experiment for the measurement of specific and latent heat Experiment for the measurement of the equivalent mass
3 Polystyrene glasses 3 Polystyrene glass lids	Experiment for the measurement of specific and latent heat Experiment for the measurement of the equivalent mass
Galileo's trampoline (4 pieces to assemble)	Experiment on parabolic motion
2 Sheets of carbon paper 150 cm Tape measure Metal marble (8 mm diameter)	Experiment on parabolic motion
Smartphone holder	Beer's law experiment (concentration of the medium) Experiment on parabolic motion Experiment on Newton's law of cooling
Hook with 8 nuts Spring Base with hook 1 m long twine	Hooke's law experiment

(continued)

Table 1 (continued)

Components of the Home Kit	Experiments in which they are used
1 10-Sided die 1 20-Sided die	Experiment on macrostates and microstates
50 cm Ruler	
Diffraction grating	
Rectangle of coloured plexiglass	
Additional material	
Sheets of white paper	Black cardboard
Black adhesive tape	Supports
Metal pots/containers	Smartphone

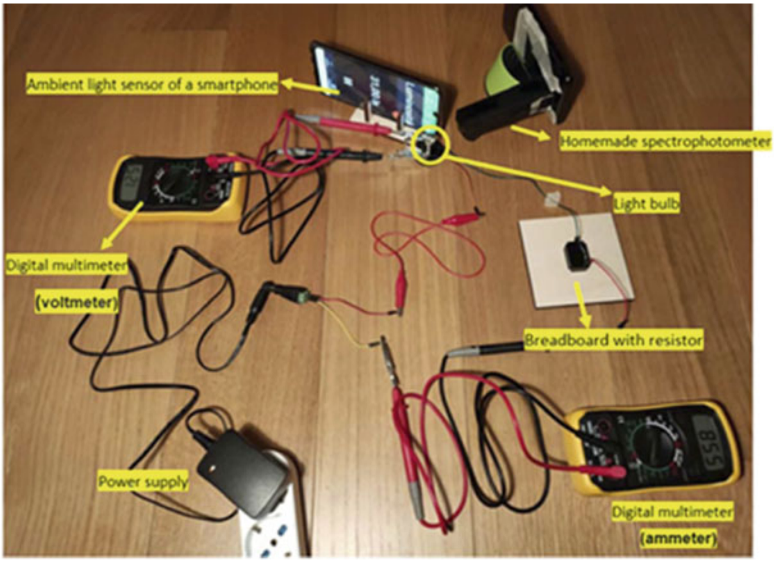


Fig. 2 Experimental apparatus for quantitative experiments about blackbody radiation (Onorato et al. 2021a, b) as photographed by one of the students

results of their answers can be seen in Fig. 4, where a comparison between the different methodologies is depicted. The Home Kit was one of the most appreciated methods.

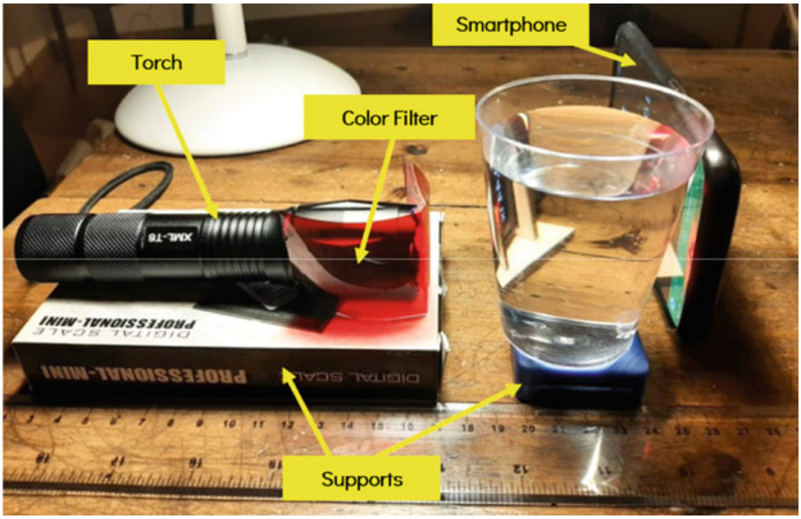


Fig. 3 Experimental apparatus for quantitative experiments about the Beer's law (concentration)

6 Conclusions

We can now try to answer our research question based on the findings of this study:

Can a hands-on Physics Lab be delivered effectively as a distance Lab using a Home-Kit?

Of course, our small experience cannot give a complete answer to this question. At the same time, we can say that our experience as teachers has been very satisfactory, using the Home-Kit, and the students seem to find this methodology both effective and engaging. As a last note, when compared to past traditional on-campus laboratory courses, we discovered that our online laboratory courses led to somewhat equivalent final grades and general laboratory competences shown by students in the preparation of a final personal project presented and during the examination. More importantly, the results from the student questionnaire show that key learning objectives were satisfied, student satisfaction with the remote lab was maintained and effective collaboration via video-conferencing breakout rooms was achieved.

We would like to finish this work by underlining that not only does the use of the Home-Kit provide an answer to a laboratory course conducted through distance learning, but it can also serve as an opportunity to use low cost material to perform many experiments, with results that are usually achieved by higher-cost instruments. Home-Kits can also be given to students at university and in schools in order to help with homework. They can even be of help to students in their preparation for a final exam, for example, through the presentation of a personal project.

Table 2 Students' answers related to Learning Goals (LG) of the course, difficulties encountered and course effectiveness. Answers were given in a Likert scale from 1 to 5

Question #	Dimensions—learning goals, difficulty and effectiveness	Questions 1—Strongly disagree 2—Disagree 3—Neutral 4—Agree 5—Strongly agree	Home Kit	Oglethorpe University
1	Difficulty	Having to do the experiments by myself at home was harder than in a group onsite in the lab	3.3	4.5
2	Effectiveness	I feel that I learned as much through this online experience as I would have in a face-to-face lab	2.8	3.1
3	LG 1 Construct knowledge and a deeper understanding of physics via direct experience	My experiences with the lab kits will help me apply physics concepts to novel situations	4.2	3.8
4	LG 2 Develop practical skills in running experiments/trials, problem-solving and troubleshooting of experiments	As a result of running all experiments by myself, I feel I now have better troubleshooting skills for real-world experiment situations	3.5	4.2
5	LG 3 Demonstrate experimental design and analysis of data	The kit experiments and extensions helped me learn experiment design	3.9	4.0
6	LG 4 Understand the nature of scientific measurements (repeatability, uncertainty, bias, and precision)	The kit experiments helped me understand the nature of scientific measurements (repeatability, uncertainty, bias, precision)	3.6	4.2
7	LG 5 Develop scientific habits of mind (critical thinking)	The kit experiments allowed me to develop critical thinking for laboratory experiments	3.8	3.9

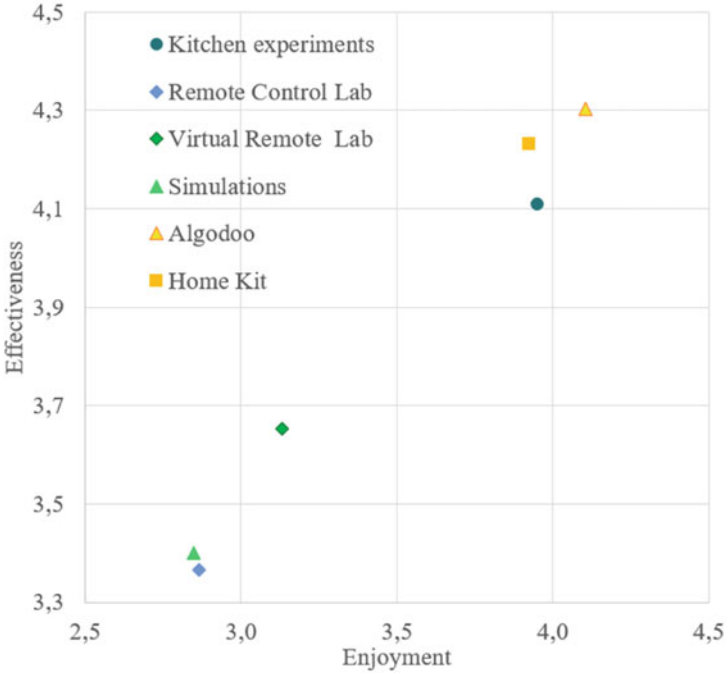


Fig. 4 Comparison between different methodologies as part of the questionnaire given to the students at the end of the course

Acknowledgements The authors acknowledge the COSID-20 project of the University of Trento which allowed the design and development of the Home-Kit which is at the centre of this work.

References

Campari EG (2021) Physics laboratory at home during the COVID-19 pandemic. Phys Teach 59:68–71

Fox MFJ, Werth A, Hoehn JR, Lewandowski HJ (2021) Lab instruction during the COVID-19 pandemic: effects on student views about experimental physics in comparison with previous years. Phys Rev Phys Educ Res 17:010148

Fox MFJ, Werth A, Hoehn JR, Lewandowski HJ (2020) Teaching labs during a pandemic: lessons from Spring 2020 and an outlook for the future. arXiv:2007.01271

Howard D, Meeting MM (2021) Laboratory course learning goals remotely via custom home experiment kits. Phys Teach 59:404

Lucisano P (2020) Fare ricerca con gli insegnanti. I primi risultati dell'indagine nazionale SIRD "Per un confronto sulle modalit'a di didattica a distanza adottate nelle scuole italiane nel periodo di emergenza COVID-19." Lifel Lifew Learn 16:3–25

Moosvi F, Reinsberg SA, Rieger GW (2019) Can a hands-on physics project lab be delivered effectively as a distance lab? Intern Rev Res Open Distr Learn 20

Nancheva N, Stoyanov S (2005) Simulations laboratory in physics distance education. In: Proceedings of the workshop on multimedia in physics teaching and learning

Onorato P, Rosi T, Tufino E, Caprara C, Malgieri M (2021a) Using smartphone cameras and ambient light sensors in distance learning: the attenuation law as experimental determination of gamma correction. Phys Educ 56:045007

Onorato P, Rosi T, Tufino E, Caprara C, Malgieri M (2021b) Quantitative experiments in a distance lab: studying blackbody radiation with a smartphone. Eur J Phys 42:045103

Sukariasih L, Erniwati LS, Hariroh L, Fayanto S (2019) Studies the use of smartphone sensor for physics learning. Int J Sci Technol Res 8:862–870

Zvacek SM, Simonson M, Smaldino S (2019) Teaching and learning at a distance: foundations of distance education, 7th edn. IAP

Teaching Approaches to Facilitate Learning

The Influence of Arduino-Based Student Experimentation on the Development of Students' Skills and Competences

Dorottya Schnider and Mihály Hömöstrei

Abstract The process of educational development requires the use of new ideas in addition to traditional techniques. In the field of physics education, it is necessary to extend our methodological toolbar in order to teach effectively even under the changed conditions—technological development, changing curricula—and provide students with the same quality of education. Arduino-based student experimentation is an implicit way of learning, which gives the opportunity to students to work in small groups and conduct experiments with the application of modern digital devices. It involves students completely in the work processes and develops those skills and competences that are essential for a successful member of the society. The method we developed encourages students to participate actively in their learning processes and acquire knowledge by observing, describing and understanding different phenomena. The overall aim of our study is to present an Arduino-based method, where a digital device helps to improve physics teaching. Meanwhile, we map the competencies of the physics teachers that have to be improved for such a teaching project. The project pointed out that there is a demand for the development of TPACK—Technological Pedagogical Content Knowledge—courses in physics teacher education.

1 Introduction

The shortage of human resources in the fields of technology and science in Europe has now become one of the main obstacles to economic development. In public education, it is necessary to open up to new fields, as the changed conditions—the needs of

---

D. Schnider (✉) · M. Hömöstrei
Faculty of Science, Department of Materials Physics, Eötvös Loránd University, Institute of Physics, Budapest, Hungary
e-mail: schniderd@f.fazekas.hu

D. Schnider
Fazekas Mihály Primary and Secondary School Budapest, Budapest, Hungary

M. Hömöstrei
Deutsche Schule Budapest, Budapest, Hungary

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2023

J. Borg Marks and P. Galea (eds.), *Physics Teacher Education*,
Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-44312-1_14

Generation Z (Seemiller and Megan 2017) students, their individual characteristics, technological development, changes in skills necessary for successful life orientation, low number of lessons—require broadening the methodological toolbar.

In order to enhance the popularity of physics among students, the application of techniques and methods considered successful in other fields can be a good solution by promoting an internationally successful approach in Physics education. The process of educational development requires the use of new ideas in addition to traditional techniques, and the development and testing of new methods and tasks.

1.1 The Changing Concept of Knowledge

The concept of knowledge, the process of knowledge transfer, and the assessment of student performance change according to changing needs and skills. International summative assessments, e.g., PISA tests (Dossey et al. 2000), primarily assess the quality of the acquired knowledge, evaluate skill acquisition, and analyze whether students have the competencies that are essential for life as well as for employment. These tests measure whether students can apply what they have learned. The aim of education is to ensure the acquisition of practical knowledge. In education, therefore, the use of lifelike, practice-oriented opportunities is emphasized. Knowledge is developed through sufficient experience (Csapó 2004, 2007; https://www.leifiphysik.de/).

In education, not only is the quantity of knowledge important, but also its quality. The goal is to develop students' cognitive skills and provide them with applicable knowledge. As a teacher, it is worthwhile to plan our lessons along with operators (competence elements) that ensure the availability, understanding, practice, and application of knowledge (Sokoloff 2006). Teacher-centered education and frontal teaching should be complemented by a learner-centered education that is based on competence development and in which the students deepen their knowledge through active participation in the learning process (Csapó 2004, 2007; https://www.leifiphysik.de/). Physics is an empirical subject; knowledge is determined by previous knowledge, observation, and experiences.

1.2 Physics Curriculum—Goals of Physics Teaching

The role of student experimentation has been enhanced. Curricula—in addition to the Hungarian National Core Curriculum (https://eacea.ec.europa.eu/national-policies/eurydice/content/teaching-and-learning-general-secondary-education-2_en)—articulate the importance of qualitative interpretation of phenomena, description and explanation of data, as well as quantitative description. Being able to predict processes, build a model of a phenomenon, and reflect on the expectations and outcomes can also contribute to successful life orientation.

Practice-oriented education ensures the possibility of more successful knowledge transfer and competence development. If students are completely engaged in learning and controlling their own learning processes, and participate actively in an activity-based physics class, they build and shape their knowledge themselves throughout experiments. Within this new approach, the teacher plays the role of the tutor (Neville 1999) who organizes learning processes in a controlled way, monitors students' activity, and develops skills and competencies. In an activity-based lesson, students are actively involved in building their own knowledge with appropriate teacher coordination (Szalay and Tóth 2016), even in an informal environment—e.g., at home.

1.3 Lesson Planning

Based on Bloom's taxonomy (Fig. 1)—a requirement-based, goal-oriented system—the expected output can be achieved by ensuring students the necessary, logically connected steps that are required for acquisition, e.g.,: presentation, description, explanation, practice, application, evaluation, production, etc. Planning lessons according to the requirement system ensures that the efficiency of the teaching and learning process can be enhanced while developing skills that enable the application of the acquired knowledge. The taxonomy can be used as a framework for designing lessons and control learning processes by helping teachers identifying the expectations and requirements of the course (https://citt.ufl.edu/resources/the-learning-process/designing-the-learning-experience/blooms-taxonomy/).

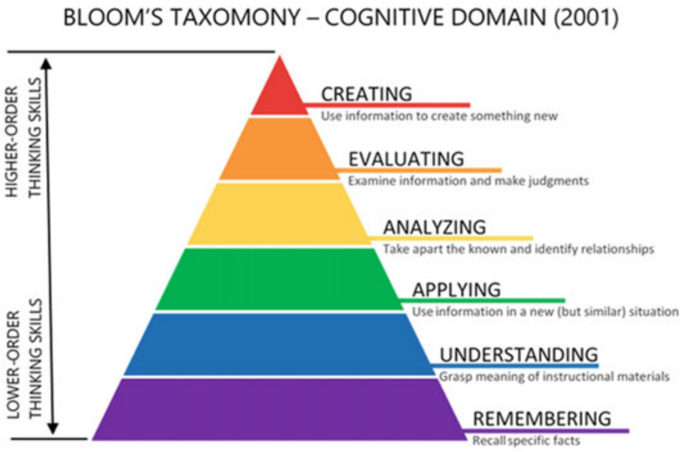


Fig. 1 Bloom'-taxonomy: classification of learning outcomes (https://citt.ufl.edu/resources/the-learning-process/designing-the-learning-experience/blooms-taxonomy/)

2 Aim of the Study

The aim of our study is to present and promote a teaching method—competence-based physics teaching—that we have developed and tested, which highlights the importance of student experimentation, and supports teachers in creating a safe learning atmosphere and a natural environment which gives the opportunity for students to acquire practical and applicable knowledge. Through practice-oriented methods, students work on task-based activities—e.g., student experiments and measurements organized in group work—and deepen their previously acquired knowledge. The method gives teachers the opportunity to develop those competences—both social and physics skills—that are essential for everyday life, and later for the world of work.

The method encourages students to take part actively in their learning processes and acquire knowledge by observing, describing, and understanding different phenomena. Teachers monitor the learning process by providing a logically-structured way for students to reach the appropriate level while developing skills. In our study, we share a good practice—Arduino-based (https://www.arduino.cc/) opportunity for classroom experimentation—that proved to be successful in our teaching practice, and investigate its role in competence development and the acquisition of necessary knowledge. According to the results of one of our previous investigations, digitalizing traditional methods in education does not contribute to cognitive development (Schnider and Hömöstrei 2021). There is a need to apply digital devices based on methods designed for digitalized education. According to our hypothesis, the effective use of digital tools may not only play an important role in motivating students, but also in active learning and competence development, too. Our study emphasizes a method that was developed to support digitalized physics lessons in particular: digital measurements, data processing, data analysis, etc. For this, we applied Arduino-controlled sensors, because they are affordable, allowing teachers to build numerous low-cost scientific instruments and experimental setups for the physics laboratory. This way, students have the opportunity to work in small groups and focus completely on conducting experiments with the groups' own mobile device, while competence development takes place. Students can easily build the circuits and write simple program codes to operate the sensors for the measurements. After the measurement, data is analyzed digitally—students represent data graphically using Excel. For the effective way of teaching, the development of digital competences of teachers in science (https://dikolan.de/en/) is required, too. It is necessary to implement TPACK—Technological Pedagogical Content Knowledge (Kurt 2019)—in physics teacher education.

3 Research Method and Research Design

3.1 Method

Empirical research to address the questions mentioned above wasorganized in the school year 2019/2020. The research was carried out in Budapest, in Fazekas Mihály Primary and Secondary School among 45 7th graders. The basis of the research was a pilot project that aimed to investigate the influence of the developed teaching method—learner-centered digitalized student experimentation—on students' competence development. The investigation was conducted with experimental (test) and control groups. A preliminary test (pre-test) was used to observe any significant differences in the experimental and control groups of students' knowledge. Post- and follow-up tests were used to assess students, gather data, and identify any effects of the applied methods on students' academic performance—competence development, and long-term information processes.

3.2 Sample

The authors organized the students into two groups. The test group (27 students) consists of seventh-graders, who got into the school after taking preliminary examinations. As the curriculum states, the students of this class have only one 45-min-long physics lesson per week. The control group (18 students) consists of students from the parallel class. They take part in primary school training so they are required to attend two physics classes per week. The basis of our research is the conscious application of Arduino-based classroom experiments and the investigation of the influence of it on students' skill development. Both of the classes have the same physics teacher.

3.3 Research Questions (RQ-S)

The teaching experience of the authors confirmed that it is worth investigating the research problem-based on the following research questions:

(1) What kind of techniques can support physics teachers in their use of digital technology in a meaningful way in the classroom? How should Arduino-supported lesson plans be designed?
(2) How does Arduino-based student experimentation—conducted according to the competence-based method—contribute to the students' skills and competences?

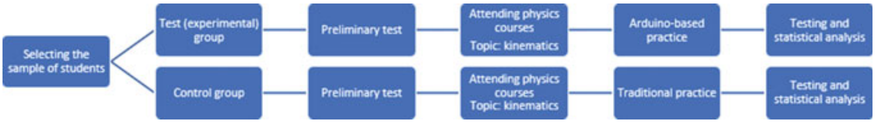


Fig. 2 The research model

3.4 Research Model

The research model can be seen in Fig. 2.

3.5 Instruments

Learning stages Experimental and control groups attended the same traditionally organized kinematics lessons, and they got the same instruction—the theory was explained by the teacher (frontal teaching), but in the practice stage, the teacher used different methods in the two groups. The members of the test group had the opportunity to take part in lessons organized according to the competence-based physics teaching methodology developed by the authors. It offered a form of task-based practice. The students of the experimental group conducted experiments and measurements in groups of 4. Students from the control group solved traditional counting tasks as practice.

The project During the research, the students of the test group performed experiments and measurements in small groups using the possibilities provided by modern measurement technology—Arduino, Arduino-controlled sensors, and digital data analysis—in the physics lessons.

Lesson planning During the project, the authors designed lesson plans based on the Bloom's taxonomy mentioned above. They formulated tasks based on the learning outcomes, namely those competences that they wanted to develop.

Figure 3 shows the method the teacher followed during the organization of the Arduino-supported activities.

The students were introduced to Arduino and its kit at the beginning of the investigation. Simple experiments (e.g., programming LEDs to flash for an appropriate period) were performed in groups in order to learn how to use the device; learn simple program codes that operate the sensors and set up the experiment, understand the circuit diagrams, etc. In order to develop students' cognitive skills and

Fig. 3 The organization of Arduino-supported student experimentation

processes the authors designed a task sheet for each lesson. The aim of the tasks was to support students in deepening their knowledge by allowing them to describe phenomena, understand and evaluate steps, practice, design, and create. The teacher as a tutor monitors learning processes and provides them with logically connected steps that help students to achieve higher levels of competence. The worksheets were formulated on the basis of the levels of the Bloom taxonomy and even provided the possibility of creation and production—as differentiation for the faster students. Experimenting, measuring, and collecting data with Arduino is more than just a hands-on experimentation. They have to learn to use and program the devices, even if at the beginning, the groups had to set up the experiment-based on instruction and circuit diagrams. They had to interpret and explain the given program codes. Then they were expected to create circuits without relying on a diagram, and write code independently based on description. During the learning process, students were able to solve more complex problems. The most talented ones were able to design their own experiment methods at the end of the project. In addition, students need to know basic program codes and basic circuits in order to easily solve more complex problems based on solid foundations. Our method enables students to reach a more abstract level of knowledge by solving increasingly difficult tasks from the basics. Competence development takes place during this process. It is important to make sure during lesson planning that the chosen techniques and activities—in this case, the questions of the worksheet—serve the development of students' skills and competencies. The aim of practice-oriented, task-based, teacher-supported student experimentation in groups is to develop both soft- and hard skills.

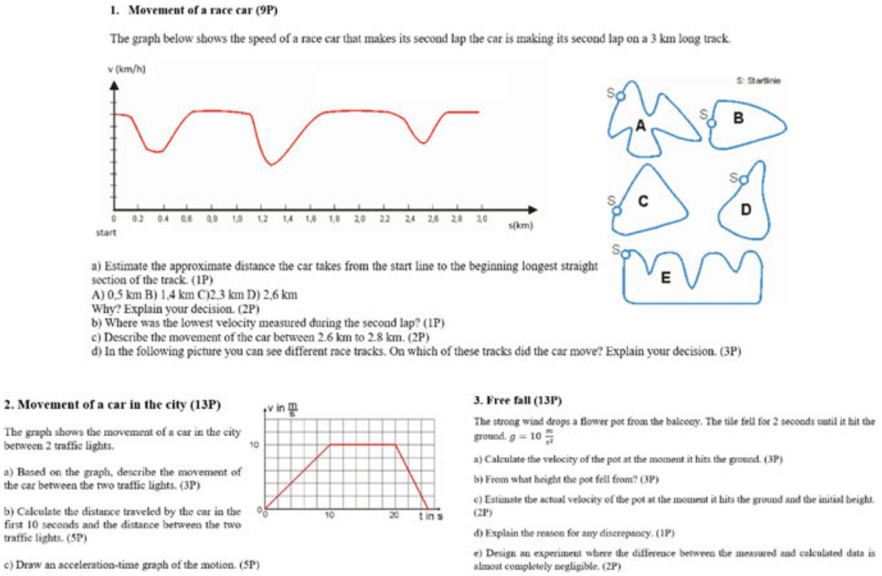
The tasks At the beginning of the project, students were introduced to Arduino and its use by completing beginner level tasks. The students made simple circuits based on the description and diagram, and got acquainted with some basic program codes. The codes were given in advance, and the students had to interpret and type them to operate the sensors. In the introductory lesson, they programmed LEDs for lighting and then for flashing for a given period. Then, based on the basics (knowledge gained by solving the introductory problems), we expected students to perform more complex operations, e.g., program 3 LEDs independently based on the task description so that they work as traffic lights, and the groups had to draw the circuit diagram as well. The most talented groups of students had the opportunity to solve bonus problems, e.g., program two traffic lights that control cross-road traffic. The subtasks for each task were intended to facilitate interpretation, description, and the development of estimation and planning competencies.

After the introduction, the students were able to move on to learning Physics. Following a similar format, the groups were given a worksheet with guided questions to facilitate an effective learning process. Students programmed a photoresistor and plotted the measured values with the Arduino. The photoresistor was illuminated from a given distance with a flashlight on their cell phone. By plotting the data printed by the program, students were able to observe the relationship between light intensity and distance and they could give a qualitative explanation based on measured data. After that, the groups presented the data in a graphical form. The dependence of the brightness on the distance can be easily examined with the help of a graph. We expected students to be able to interpret the graph, formulate the relationship between quantities, analyze the measurement and list possible errors, estimate errors, and explain why the measured light intensity does not decrease to zero. Using LEDs and the photoresistor together, the groups produced a light intensity indicator. The task develops application, interpretation, and design skills, while also improving digital competence.

Within the topic of kinematics, students used Arduino for distance measurement and programmed an ultrasonic sensor in order to learn how it works, to measure distance, and to use it for the measurement of acceleration. The authors supported students with introductory tasks, then moving to the next level of competence development, the teams had to solve more complex problems—programming LEDs to indicate different distances. These tasks laid the foundation of the acceleration measurement. Acceleration measurement with the use of Arduino is faster and more accurate than measuring manually, develops skills, and can motivate students.

Tests At the beginning of the research, the preliminary test was completed in the two groups, before the first kinematics lesson. Hungarian students start learning physics in 7th grade. Before the topic of kinematics, they became acquainted with physics in general and they learned about some measurement possibilities. The authors examined the difference in physics knowledge between the members of the two groups. They compared the students' performance on previous tests and statistically analyzed the data. At the end of the unit, the students took an end-of-unit test (post-test), which contained theoretical questions and calculation tasks—e.g.: interpretation and analysis of graphs, the application of basic formulas, explanation of phenomena, estimation and experiment design, etc. Therefore, each task measured the development of a specific physical competence element. The authors wrote the end-of-unit test (Fig. 4) based on the tasks on the leifiphysik.de (https://www.leifiphysik.de/) webpage.

The authors analyzed the students' responses and applied statistical probes to investigate how the method used—competence-based physics teaching—influences the development of specific skills and competences. They completed the analytical process in JASP (https://jasp-stats.org/), checking the normality of data—the two independent samples: the scores of the test and control groups—with the use of Shapiro–Wilk test (Graham 2020). For normal distributions, the authors applied Levene's test (https://medium.com/@kyawsawhtoon/levenes-test-the-assessment-for-equality-of-variances-94503b695a57) to check whether the variances of the populations from different samples were equal or not. For equal variances, the Student-t test was applied (Pollak and Cohen 1981). In the other case, the authors analyzed the data with the Welch test (https://medium.com/@kyawsawhtoon/levenes-test-the-assessment-for-equality-of-variances-94503b695a57). If the data do not fit the normal distribution, the Mann–Whitney U test (Hart 2001) can be applied. In order to investigate the effect of different methods on the development of long-lasting knowledge, the students took a follow-up test 2 months later. It was not announced in advance, but contained exactly the same exercises as the post-test. The authors—students' teachers—knew the identities, because the students had to write their names on the answer sheets. For the analysis of follow-up test results the authors



1. Movement of a race car (9P)

The graph below shows the speed of a race car that makes its second lap the car is making its second lap on a 3 km long track.

a) Estimate the approximate distance the car takes from the start line to the beginning longest straight section of the track. (1P)
A) 0,5 km B) 1,4 km C)2,3 km D) 2,6 km
Why? Explain your decision. (2P)
b) Where was the lowest velocity measured during the second lap? (1P)
c) Describe the movement of the car between 2.6 km to 2.8 km. (2P)
d) In the following picture you can see different race tracks. On which of these tracks did the car move? Explain your decision. (3P)

2. Movement of a car in the city (13P)

The graph shows the movement of a car in the city between 2 traffic lights.

a) Based on the graph, describe the movement of the car between the two traffic lights. (3P)

b) Calculate the distance traveled by the car in the first 10 seconds and the distance between the two traffic lights. (5P)

c) Draw an acceleration-time graph of the motion. (5P)

3. Free fall (13P)

The strong wind drops a flower pot from the balcony. The tile fell for 2 seconds until it hit the ground. $g = 10\ \frac{m}{s^2}$

a) Calculate the velocity of the pot at the moment it hits the ground. (3P)

b) From what height the pot fell from? (3P)

c) Estimate the actual velocity of the pot at the moment it hits the ground and the initial height. (2P)

d) Explain the reason for any discrepancy. (1P)

e) Design an experiment where the difference between the measured and calculated data is almost completely negligible. (2P)

Fig. 4 The test. **a** 1st task, **b** 2nd task, **c** 3rd task

applied the Paired Samples t-test (Pollak and Cohen 1981) based on the p-value of the Shapiro–Wilk test.

4 Results and Discussion

4.1 Results of the Preliminary Test

The authors compared the students' performance on previous tests, calculated the mean of the grades, and investigated the distribution of them. Based on the results of the Shapiro–Wilk test, the grades of the two groups do not follow normal distribution. The p-values of the Shapiro–Wilk test are the following: $p_{\text{test}} < 0.001$ and $p_{\text{control}} = 0.033$, thus the Mann–Whitney U-test was applied. The p-value is 0.113. There is no significant difference between the two samples. The physics knowledge of the students from the different groups is similar, and there is no significant difference in their basic knowledge.

4.2 Results of the End-Of-Unit Test (Post-Test)

The analysis of student responses on the first task The first task is a PISA test exercise that presents the v-s graph of the movement of a race car. The students had to answer questions about the movement, describe and interpret the graph, and make a decision about the track of the car. The authors expected students to explain their decisions in order to measure how profound their knowledge is, and we assessed their comprehension, too. Sub-questions (a), (b), and (c) of the first task did not cause any problems for the students; members of both groups gave correct solutions. There was a significant difference between the existence, correctness, and quality of the explanation of the decision about the track of movement in exercise (d). The students had to decide which of the given options (figures) shows correctly the trajectory of the race car. Student responses—decision, explanation, and scores—are shown in Fig. 5. Students received 2 points for the correct and sophisticated explanation, e.g., if they referred to the number and quality of turns (*How sharp is the turn? What is the speed of the vehicle then?*). The total 2 points could be divided, e.g., if the student didn't give a complete explanation, but the response contained good ideas, they got 1 point. If the student interpreted the graph describing the movement correctly, but made an incorrect decision, they received the 2 points for the interpretation and explanation.

Based on the results of the Mann–Whitney test ($p < 0.01$), the members of the test group proved to be significantly better in terms of interpretation and giving explanation. Members of the test group received an average of 1.52 (standard deviation: 0.64) points for explanation, while members of the control group received only 0.56 points (standard deviation: 0.78). Several students from the control group marked typically incorrect answers. 4 students marked (a), 1 student marked (d), and 5 students marked course (e) as correct, while 1 student did not solve the task. Student decisions are illustrated in Fig. 6.

Analysis of student responses on the second task Task 2 expected students to describe the movement of a vehicle based on a graph. In addition to the qualitative interpretation, the task also required a quantitative description: Determining the distance traveled by the vehicle in the first 10 s and during the whole movement. Question (c) expected students to draw an acceleration-time graph based on their calculations.

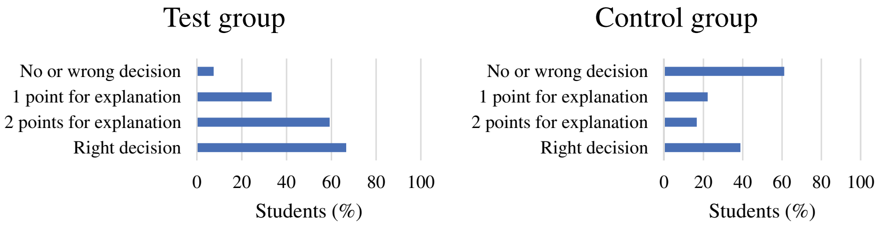


Fig. 5 Percentage distribution of student results on Task 1 (d)

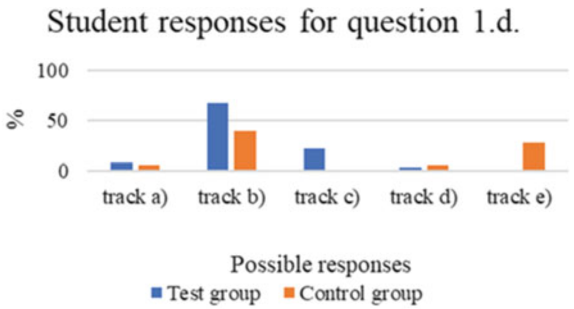


Fig. 6 Percentage distribution of student responses to question 1 (d). *Which figure shows the car's trajectory correctly?*

There was no significant difference in the interpretation of the graph (task 2.a) in the two samples ($p = 0.541$). However, there was a difference in question (2.b), the solution of the close-ended problem, and task (c), the representation of the graph. Members of the test group scored an average of 2.56 points on the problem-solving task, while members of the control group scored 1 point. Based on the p-value ($p = 0.008$) calculated from the Mann–Whitney test, the difference is significant, as in the case of the graphical representation. The test group received 1.59 (standard deviation: 1.84) points for plotting the acceleration-time graph, while the control group received 0.61 points (standard deviation: 1.33). Members of the test group performed significantly better ($p = 0.049$).

Analysis of the student responses on the third task Task 3 is complex, asking for both solving simple close-ended problems, but also assessing students' estimation and design skills.

Based on the statistical analysis of the answers, the skill of experimental design shows a significant difference ($p = 0.006$) between the two groups. There is a positive significant difference among the students of the test group. The mean score obtained for the design of the experiment was 0.85 points (standard deviation: 0.95) in the test group and 0.28 points (standard deviation: 0.57) in the control group. 16 out of 27 students from the test group answered Task (3.e)—experiment design, 13 formulated the need to reduce the air resistance, so the answers focused on the phenomenon occurring in the vacuum. 7 out of 18 members of the control group designed an experiment, but only 4 experiments met the requirements. The distribution can be seen in Fig. 7.

The results of the follow-up test By performing a Paired Samples t-test, the authors analyzed two measurements—post-tests and follow-up tests—taken from the same group. The differences between the results of the tests follow a normal distribution according to the Shapiro–Wilk test (for the test group: $W = 0.953$, $p = 0.362$; for the control group: $W = 0.951$, $p = 0.440$). Based on the results of the Paired Samples t-test, there is no significant change in the knowledge of the control group ($p = 0.067$). However, in the case of the test group, there is a significant deterioration in the storage of long-term knowledge ($p < 0.001$).

We also examined the two independent samples—follow-up test results of the test group and control group. The total scores of the students from the test group follow

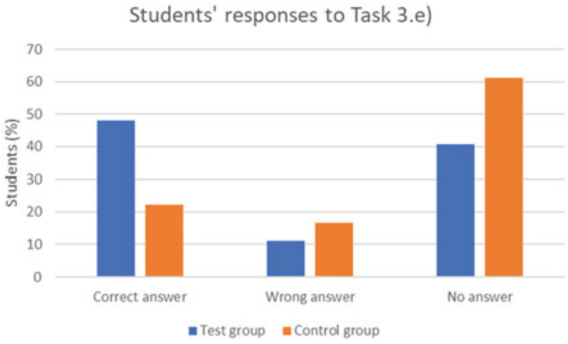


Fig. 7 Percentage distribution of students' responses to question 3 (e)

a normal distribution according to the Shapiro–Wilk test: for the test group: $W = 0.987$ and $p = 0.990$, for the control group: $W = 0.919$ and $p = 0.140$. The results of the Levene's test: $p = 0.158$, thus we relied on the Independent Samples t-test.

The value of $p = 0.037$ indicates that the students of the test group performed significantly better on the follow-up test than the students of the control group. The test group scored an average of 16.24 points (standard deviation: 7.49) and the control group scored 10.94 points (standard deviation: 4.76) on the follow-up test.

The long-term study adequately indicates the extent to which each competence element has been acquired. Compared to the control group, there is a significant positive difference in the following hard skills of the students from the test group: graphical representation of movement ($p = 0.01$) and interpretation of a given problem ($p = 0.003$). These p-values indicate the results of the Mann–Whitney-U test.

5 Conclusion

In this paper, we presented the first, small-sample phase of our research. The results show that in the case of groups of students that can be considered identical in terms of physical knowledge, there is a measurable difference in the corresponding competencies between students taught with the application of experiment-based and traditional teaching methods. We can state that the deepening of the knowledge acquired in the lessons was positively influenced by the Arduino-supported competence-based method presented in the paper, which has the special advantage of not only broadening the range of competence elements to be developed, but also increasing the proportion of successful students. The applied method and quite cheap devices play an important role in improving students' classroom participation. Using digital tools—portable, mobile devices—in designing experimental setups can involve more students in the work processes, and, based on the results, practice-oriented learning has a positive effect on academic performance. Moreover, using Arduino develops those skills that are necessary to have in the twenty-first century: digital measurement, data processing, graphical representation, data analysis, designing setups, creating new measurement instruments, etc. Although the method's presumably positive effect on long-term knowledge was not seen in the project—which included a few physics lessons—on the follow-up test, students in the test group performed worse than previously on the post-test, but they still proved to be significantly more successful than students who attended traditional classes. Our goal is to develop our method in order to facilitate the acquisition of quality, long-term knowledge.

The results of our research indicate that the developed method supports task-based learner-centered Physics education, the application of acquired knowledge (graphical representation, solving numerical tasks) and its practical use (design of an experiment), as well as understanding and interpretation (justification, explanation). The results indicated that there is a demand for the development of TPACK courses in physics teacher education.

Acknowledgement Prepared with the professional support of the Doctoral Student Scholarship Program of the Co-operative Doctoral Program of the Ministry of Innovation and Technology Financed from the National Research, Development and Innovation Fund.

This work is supported by the Research Program for Public Education Development of the Hungarian Academy of Sciences (Project Number: SZKF-7/2022).

References

Csapó B (2004) Knowledge and competencies. In: Letschert J (ed) The integrated person. How curriculum relates to new competences

Csapó B (2007) Research into learning to learn through the assessment of quality and organization of learning outcomes. The Curric J 18(2):195–210. https://doi.org/10.1080/09585170701446044

Dossey J, Csapo B, de Jong T, Klieme E, Vosniadou S (2000) Cross-curricular competencies in PISA towards a framework for assessing problem-solving skills. In: Fourth general assembly of the OECD education indicators programme (Tokyo), pp 19–41

Graham D (2020) Checking for normality in JASP: https://www.youtube.com/watch?v=41eOkYHkRSQ

Hart A (2001) Mann-Whitney test is not just a test of medians: differences in spread can be important. BMJ (Clin Res Ed.) 323(7309):391–393. https://doi.org/10.1136/bmj.323.7309.391

JASP software for statistic analysis: https://jasp-stats.org/

Kurt S (2019) TPACK: Technological pedagogical content knowledge framework. Educ Technol

Neville AJ (1999) The problem-based learning tutor: teacher? facilitator? evaluator? Med Teach 21(4):393–401. https://doi.org/10.1080/01421599979338

Pollak M, Cohen J (1981) A comparison of the independent-samples t-test and the paired-samples t-test when the observations are nonnegatively correlated pairs. J Stat Plan Inference 5(2):133–146. https://doi.org/10.1016/0378-3758(81)90023-9

Schnider D, Hömöstrei M (2021) Hagyományos vagy digitális? Melyik a nyerő? Fizika Házi Feladatok Papír Alapon És Digitális Módban Fizikai Szemle 71(3):97–101

Seemiller C, Megan G (2017) Generation z: educating and engaging the next generation of students Sage. J 22(3):21–26. https://doi.org/10.1002/abc.21293

Sokoloff (2006) Interactive lecture demonstrations: active learning in introductory physics. Wiley

Szalay L, Tóth Z (2016) An inquiry-based approach for traditional 'step-by-step' experiments. Chem Educ Res Pract 4. https://doi.org/10.1039/c6rp00044d

The Hungarian National Core Curriculum https://eacea.ec.europa.eu/national-policies/eurydice/content/teaching-and-learning-general-secondary-education-2_en

University of Florida Bloom's Taxonomy https://citt.ufl.edu/resources/the-learning-process/designing-the-learning-experience/blooms-taxonomy/

https://www.kmk.org/fileadmin/Dateien/pdf/Bildung/Auslandsschulwesen/Kerncurriculum/Auslandsschulwesen-Operatoren-Naturwissenschaften-02-2013.pdf

https://www.arduino.cc/

https://dikolan.de/en/

https://www.leifiphysik.de/

https://www.statology.org/welchs-t-test/

SVELAMI-B Project: Online Physics Activities Within STEM Education

Daniela Di Martino, Laura D'Alfonso, Nadia Malaspina, and Silvia Penati

Abstract The SVELAMI-B project was designed to offer in-depth activities in the STEM field to primary school children and secondary school boys and girls, entirely in distance learning. Starting from famous discoveries by women scientists organized in a well-designed multidisciplinary set-up (from physics, to mathematics, computer science, geology, and education science) the aim of this project was to enhance the learning potential of scientific subjects among young students and increase the attraction of girls towards STEM disciplines. Some specific examples of conducted activities will be presented, as well as possible developments for the design of new school interventions starting from a community of practice.

1 Introduction

There are several overlapping factors which limit women's participation and career in Science, Technology, Engineering, and Math (STEM) disciplines. Consequently, the underrepresentation of the female gender in STEM is a compelling issue (Wassell et al. 2017). Results of the latest Trends in International Mathematics and Science Study (TIMSS Mullis et al. 2020)) clearly depict the current gap between young men and young women in scientific and technological learning, and in Italy the gap is wider than in other Organization for Economic Co-operation and Development (OECD) countries.

The SVolgere Esperimenti nei LAboratori di MIlano-Bicocca (SVELAMI-B) project is an Italian project coordinated by the Physics Department of the University of Milano-Bicocca, with the participation of four other Departments of the same University, designed within the STEM 2020 call (Department of Equal Opportunities

---

D. Di Martino (✉) · L. D'Alfonso · S. Penati
Physics Department, University of Milano-Bicocca, Piazza della Scienza, 3, 20126 Milan, Italy
e-mail: daniela.dimartino@unimib.it

N. Malaspina
Department of Earth and Environmental Sciences, University of Milano-Bicocca, Piazza della Scienza 4, 20126 Milan, Italy

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2023

J. Borg Marks and P. Galea (eds.), *Physics Teacher Education*,
Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-44312-1_15

of the Italian Government Presidency of the Council of Ministers). The whole project was carried out online in 2021—due to the continuation of the COVID-19 emergency. It mainly aimed at offering several actions and activities among STEM subjects (in particular, Physics, Earth Sciences, Mathematics, and Computer Science) to primary school children (3rd and 4th grade) and secondary school (11th and 12th grade) boys and girls, with a particular attention to the gender gap issue. Most students were of female gender, with 44 girls out of 73 elementary school participants and 92 out of 139 secondary school participants.

In the following sections, the design of the project will be presented. In the case of primary schools, the activities were part of the usual school activities, whereas at the secondary schools, the project was carried out in "extracurricular" hours.

2 Physics in STEM Education, with Attention to the Gender Gap Issue

The project was designed within a multidisciplinary community of practice based in the University of Milano-Bicocca. SVELAMI-B aimed to contribute to increase young people's interest in STEM disciplines and at the same time raise awareness of the existence and possible overcoming of gender stereotypes that affect the choice of schooling in this area. The project has benefited from previous experiences, widespread and consolidated, both at a national and international level, in gender-sensitive science dissemination activities.

Among the recently organized activities at Milano-Bicocca University, the conference "Women in Sciences" (https://www.unimib.it/eventi/women-sciences-scienze-d-maiuscola), addressed to secondary school, bachelor and master students, along with doctoral students, the "Discover the Female Scientists" booth during the European Researchers' Night "Meet-me-tonight 2019" (https://www.fisica.unimib.it/it/eventi/meetmetonight-%E2%80%93-faccia-faccia-ricerca), and the events related to the "Women's talents", promoted by the Municipality of Milan, and dedicated to women's talents, from the exemplary figures of the past to the excellence of today, protagonists in the world of art, culture, entrepreneurship, politics, sport, and science (https://www.unimib.it/eventi/un-giorno-tra-scienziate-in-bicocca).

Moreover, the Milano-Bicocca University Departments involved in SVELAMI-B are members of ABCD (https://abcd.unimib.it/english-description/), an interdepartmental consortium for gender studies.

Following inquiry-based principles (see for example Pedaste et al. 2015, and references therein) we developed a path trying to attract female students, also by offering them a role model. In fact, most of the SVELAMI-B staff were female scientists of the University of Milano-Bicocca. Moreover, the female contribution to Science in the past history was emphasized to provide students also with female models, so passing the message that Science requires intellectual qualities independent of gender. The work of several famous female scientists was presented to both primary and secondary schools. For primary school students, we prepared videos of our laboratory activities preceded by the comic story of a famous female scientist of the past. Concerning Physics, topics were chosen mainly within core aspects defined in the "A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas" (National Research Council 2012).

For the primary schools, we proposed several remote scientific experiments in the areas of Physics (the mysteries of the universe, the light, and radioactivity), Computer Science (computers and their language, artificial intelligence, and machine learning), Mathematics (cryptography and theory of codes, seven questions and a lie) and Earth Sciences (minerals and their interaction with light, earthquakes, and volcanoes, how the mountains are built). Each experiment was preceded by a brief introduction (often presented with the aid of videos, images, and stories), then children were asked to perform the experiment at school or at home and the results were discussed paying careful attention when the first discovery of that phenomenon was made by a woman scientist who has not been given full credit. Further details of the primary school activities are discussed in Di Martino et al. (2022).

For secondary schools, virtual laboratory experiences have been developed, covering the areas of Physics, Computer Science, Mathematics, and Earth Sciences, with the same modalities of elementary schools, remodulated with respect to the content and the training course. The physics topics were chosen according to National Research Council (2012) and many of the experiments were possible thanks to the LabEx laboratory (see next paragraph) at the Physics Department of the Milano-Bicocca University.

Table 1 lists the proposed experiments.

2.1 LabEx Experience

Many of the proposed experiments exploited the facilities of LabEx (labexbicocca.it), a laboratory based in the Physics Department of the University of Milano-Bicocca within the PLS (Scientific Degrees Plan) promoted by the Ministry of University and Research.

The goal of LabEx is to bring students closer to the world of science and to understand and apply the so-called "scientific method": by their firsthand involvement in setting up, performing, and commenting on the results of different experiments we aim to stimulate in them a process of critical analysis of the observed phenomena. The experiments can be carried out by small groups of high school students (3–5) under the guidance of bachelor, master, and doctoral physics students, with the collaboration of their teachers and staff of the Department of Physics.

Different experiments are proposed in which students will try to verify the existence of the fundamental forces of nature; some laboratory experiences will allow a first soft approach to the world of physics while in other experiences they will replicate some experiments considered fundamental in the history of physics.

Table 1 A simple description of the proposed physics experiments

Topic	Description
(1) Electromagnetic interaction	We will describe the research on electromagnetic phenomena, also inspired by the work of Laura Bassi, and we will replicate the most famous experiments that in the early nineteenth century marked the beginning of a new era in physics. The Hertz experiment to verify the existence of electromagnetic waves will be replicated
(2) Waves in solids	Various experiments will be proposed to study the propagation of microwaves and the phenomena of interference and diffraction of microwaves in solid materials
(3) Elementary constituents of matter	The students will replicate the experiment of J.J. Thomson that in 1897 led to the discovery of the electron
(4) Dualism wave—corpuscle	Experiments on radiation-matter interference will be performed, followed by a discussion of wave-body dualism in quantum mechanics
(5) The speed of light	A simple experiment will be performed to determine the speed of light. The role of this physical quantity in Einstein's formulation of special relativity will be discussed
(6) Gravity	Experiments will be performed to investigate the properties of the gravitational interaction. Experiments on space–time curvature will aim to understand the foundations of Einstein's theory of general relativity
(7) Cosmic rays	The use of a spark chamber will reveal the presence of cosmic rays that continuously hit the Earth. Quantitative cosmic ray measurements will be made with a new, compact ArduSiPM instrument. The important role of research activity in astrophysics by famous female scientists such as Margherita Hack and Vera Cooper Rubin will be discussed

2.2 Multidisciplinarity

All the STEM experiences were carried out in a multidisciplinary and interconnected educational path, since the community of practice of Milano-Bicocca University is a real multidisciplinary community. Multidisciplinarity has the advantage to explore phenomena by different points of view. As an example, part of the laboratory activities of Earth Sciences, such as the observation of minerals and rocks under the microscope, required the complementary knowledge of the properties of light and its interaction with matter previously introduced by the Physics experiences. Students learned and experimented the decomposition of white light and light refraction and applied their results in the optical properties of transparent birefringent minerals, both at the macro- and microscale. The formation of interference colors using a (virtual) microscope with polarized light allowed students to see a rock of the Alps in transparency and identify its mineral composition and structure deformations. Moreover, they were able to interpret the behavior of waves in solids with various experiments proposed to study the propagation of microwaves, and phenomena of interference and diffraction of microwaves in solid materials. This physical experience was then compared with the geophysical behavior of propagation of seismic waves formed after an earthquake and their use in the study of the inner Earth, relating the story of Inge Lehman, the first woman in geophysics that discovered that the outer core is liquid.

In a parallel way, the topic of light was treated from "a physical point of view", starting from simple experiments with light, as with the capture of rainbows, progressing with the use of established teaching tools (such as the phet.colorado.edu/it/) and at last approaching "difficult" phenomena such as diffraction, polarization, diffusion, under different aspects to stimulate curiosity and give different insights into the phenomena (making connections to the previous part of Earth Science for light under the microscope and the study of rocks).

2.3 Students' Engagement and Digital Technologies

The COVID-19 pandemic has affected school education globally, and one of the SVELAMI-B goals was to create meaningful collaborations with non-formal and informal science organizations. Before the beginning of the activities, the path of the project was shared and agreed with the class teachers. Some tutors (Bachelor, Master's or PhD students) were involved in the project to help participants in data analysis, comments on the experiences, and shared perspectives.

Due to the pandemic period, SVELAMI-B was designed remotely, and the use of digital platforms was mandatory. However, despite the limitations of being at distance, the digital platforms were well-known among the participants (even at primary schools). We kept a specific attention to the time spent in computer-based activities, and we offered several breaks within the experiences.

Padlets were used during the presentation of the experiments to encourage an interactive dialogue with the students and platforms such as Kahoot in synchronous and asynchronous mode (Kahoot challenge), Wooclap, and other specific platforms were exploited to receive feedback stimulated by online discussion. Many activities were carried out in groups (the WebEx platform offers a specific option, to select breakout sessions). All the students, both primary school children and high school boys and girls, were required to compile a "logbook" at the end of each activity, reporting their feedback (scientific learning and social experience) and suggestions.

A particular topic that was proposed is The Great Challenges of the Universe: a presentation and discussion on what are the main natural phenomena that are not yet understood, from dark matter, dark energy, how the Universe evolves, gravity at small distances, black holes, to the size of space–time, the Solar System and the formation of the Earth, the origin of the atmosphere, and what are the most accepted theoretical models. The discussion took also some cues from some statements in the television series "The big bang theory", starting from the title, with the intent to explain and interpret them. Episodes of the series were a stimulus for an in-depth examination of the transversal and interdisciplinary nature of gender stereotypes and unconscious biases from which the scientific world is not exempt.

For the laboratory experiments, the use of established digital teaching tools was highly effective. One of these is the PhET (interactive simulations for science and mathematics at the University of Colorado, Boulder, phet.colorado.edu/it/). Concerning the geophysical behavior of rocks (and polarization effects) an important digital tool was the Virtual Microscope (VM) (https://www.virtualmicroscope.org/), an Open Educational Resource (OER). The VM project aims to make a step change in the teaching of Earth Sciences by broadening access to rock collections that are currently held in museums, universities, and other institutions around the world, and allowing microscope observations at a distance.

2.4 Educational Enhancement of the Activities

A working group of the Department of Human Sciences for Education has offered didactic support to teachers who joined the project, according to the following operational plan:

(1) Before the beginning of the activities, together with the teachers and the operators involved in the realization of the project, the used methodologies were discussed in order to allow the active participation and interactivity of boys and girls, to let the educational experience become really meaningful and effective for the whole group.

(2) At the end of the activities, a discussion about the scientific experiences and the proposed material was planned, aimed at identifying the conceptual nodes involved and integrating them into a broader curriculum according to Dewey's principle of continuity. In this way, the scientific and operational stimuli can be enhanced from the educational point of view and become a driving force for teachers to independently design new educational experiences with children and/or young people.

3 Results, Discussion, and Perspectives

For the elementary schools, many positive effects of this project could be detected, not only among the children involved, who were active and curious, and participated with keen interest and numerous questions, but also among the teachers, as they had a real opportunity to learn and deepen their knowledge of various STEM subjects.

For high schools, the participation of the students was not always extremely active, as desired and requested by the activities, but we noticed a considerable interest in a variety of subjects presented. Moreover, SVELAMI-B activities led both primary and secondary school teachers to upgrade their digital competences. Many resources and many hints were provided to design further STEM paths, also inspired by current research in world's leading physics laboratories.

Questionnaires (administered before and after the activities) have been used to record the feelings of the participants. Some relevant answers and questions, after the meetings, are the following:

> The appropriate way to approach a research
>
> I learned a lot about the aspect regarding physics, since we only did the first two years in school, it also served me a lot of review.

In particular, for primary schools:

> Today I learned things that I would not have studied at school
>
> I would like to create a secret code to communicate with my (female) friends and I would like to know how to do
>
> Can four rainbows be seen at the same time?
>
> When Covid-19 will end, could we come to your laboratory to see the experiments live?

And for secondary schools:

> I liked the project, its content and I think it was perfectly organized. I had difficulties during the group works particularly to relate with my (male) classmates. Now I understand how our teachers feel when they do remote lectures.
>
> I like the opportunities to get involved. I want to thank the teacher for the positive comment she made me about my data presentation. I think not only that it is rewarding but also this has made me feel aware of my skills and abilities

The SVELAMI-B project put Physics (and other STEM fields) education into practice in a multidisciplinary context and at different school levels. The SVELAMI-B project displayed several strengths:

(a) varied and non-canonical content: the topics discussed were of great interest for the students, being directly related to the reality that most of them experience every day. This allowed them to make connections with what they already know (a fundamental point for the "learning process").
(b) stimulating content and activities: the proposed activities played a key role in keeping motivation alive and activating children's skills.

For the future, there are also some points to be improved, like discussing with class teachers not only the physics activities, but also how to structure the intervention by drawing on teaching methodologies and communication devices that are effective with that specific class, in order to adapt the content to the target audience.

Questionnaires (administered before and after the activities) will be further analyzed for in-depth discussions and improvements.

3.1 Gender Issue

Concerning gender issue, we report some relevant answers received:

> Today's meeting made me learn about the diversity that exists between men and women in the scientific field and it really struck a chord with me;
>
> The figure of the woman in the scientific field;
>
> The role of women in the development of scientific knowledge;
>
> Today I learned that there were female scientists
>
> Today I learned that women scientists are planning to build a car that even works without a driver
>
> In Italy did other women win the Nobel prize in addition to Margherita Hack[1] and Rita Levi Montalcini?
>
> Are women scientists many or few?
>
> What made you decide to become a scientist?
>
> What do you do when you are not studying?

In this regard, we consider the SVELAMI-B project successful since we gave a strong and clear main message: the pupils have been sensitized regarding the condition of women in the scientific field. Some little girls became passionate about science also thanks to these activities. We highlight the importance to have more female role models in the science field. As reported by Biemmi (2010, 2015), analyzing some Italian primary school textbooks, the frequency of male and female protagonists in the stories and the contexts in which they are placed are very different, and male roles always outnumber the female ones numerically.

We trust the importance of gender matching, but further initiatives should go deeper into interpersonal relationships with pupils (as suggested by Sjastaad 2012). Individual activities may not be enough and more substantial interventions should be offered.

3.2 *Replicability*

SVELAMI-B is a very ambitious project with an easily replicable path over the years following a long-term vision to propose and build together with the schools a new offer of in-depth studies of STEM subjects overcoming the barriers of stereotypes and prejudices through an approach of scientific and technologically innovative learning, from a multidisciplinary point of view (see a summary diagram in Fig. 1).

Great emphasis should still be placed on empowering primary and secondary teachers to update their digital skills. Moreover, further improvements could be foreseen to be set in place during the course of the activities, to document and analyze the cognitive processes implemented by both the children and the young people involved. More specifically, together with the teachers, also possibly organized in mixed primary/secondary working groups, we could proceed to:

---

[1] Although Margherita Hack did not win the Nobel Prize, we have deliberately left the text as written by a child.

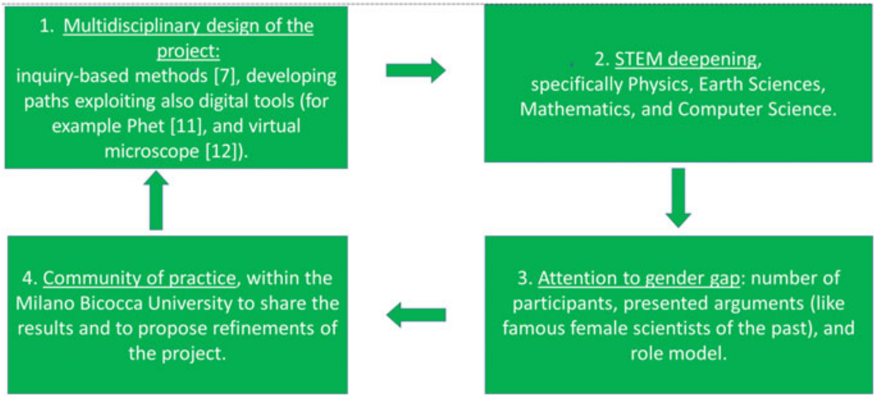


Fig. 1 Sketch of the SVELAMI-B project, and its replicability

(a) Identify, on the one hand, the knowledge learned and, on the other hand, the emerging misconceptions.
(b) Design appropriate activities and methodologies to facilitate children/youth exchange and reflection.
(c) Rethink the curriculum previously carried out, in order to re-design the educational path starting from what will emerge in the group during the experiments.
(d) Find strategies to effectively systematize the concepts learned.

The experimental activities and their theoretical descriptions could be recorded in the future throughout the implementation of the project, in order to guarantee the replicability of the educational modules in different groups.

Acknowledgements Authors wish to acknowledge all the SVELAMI-B team (Researchers, Professors and Tutors) for the fruitful and successful collaboration within the project. The Department for Equal Opportunities (Italian Government Presidency of the Council of Ministers) is gratefully acknowledged for the financial support within the STEM 2020 call.

References

Biemmi I (2010) Educazione sessista. Stereotipi di genere nei libri delle elementari. Rosenberg & Sellier, Torino

Biemmi I (2015) The imagery of gender in Italian textbooks. Research into primary school books Foro de Educación 13(18):15–35. https://doi.org/10.14516/fde.2015.013.018.000

https://abcd.unimib.it/english-description/. Accessed 31 Mar 2022

https://www.fisica.unimib.it/it/eventi/meetmetonight-%E2%80%93-faccia-faccia-ricerca in Italian. Accessed 31 Mar 2022

https://www.unimib.it/eventi/un-giorno-tra-scienziate-in-bicocca in Italian. Accessed on 31 Mar 2022 https://www.unimib.it/eventi/women-sciences-scienze-d-maiuscola in Italian. Accessed 31 Mar 2022

https://www.virtualmicroscope.org/. Accessed 31 Mar 2022

Di Martino D, D'Alfonso L, Penati S (2022) Il Nuovo Cimento 45 C, 221. https://doi.org/10.1393/ncc/i2022-22221-6

labexbicocca.it. Accessed 31 Mar 2022

Mullis I, Martin M, Foy P, Kelly D, Fishbein B (2020) TIMSS 2019 international results in mathematics and science (TIMSS and PIRLS International Study Center)

National Research Council (2012) A framework for K-12 science education: practices, crosscutting concepts, and core ideas. The National Academies Press, Washington, DC. https://doi.org/10.17226/13165

Pedaste M, Mäeots M, Siiman LA, de Jong T, van Riesen SSN, Kamp ET, Manoli CC, Zacharia CC, Tsourlidaki E (2015) Phases of inquiry-based learning: definitions and the inquiry cycle. Educ Res Rev 14:47–61

PhET resources (University of Colorado, Boulder), for interactive simulations for Science and Math, are available also in Italian at the following link: phet.colorado.edu/it/. Accessed 31 Mar 2022

Sjastaad J (2012) Int J Sci Educ 34:1615

Wassell BA, Hawrylak MF, Scantlebury K (2017) Barriers, resources, frustrations, and empathy: Teachers' expectations for family involvement for Latino/a ELL students in urban STEM classrooms. Urban Educ 52:1233–1254

Impact of New Criteria for Accreditation of Physics Degrees in the UK and Ireland: Implications for Staff Development and Support

David Sands and Robyn Henriegel

Abstract The Institute of Physics (IOP) has recently changed the criteria by which physics degrees in the UK and Ireland are accredited. The changes represent a significant shift in emphasis away from the content that must be taught to the competences and qualities that must be developed in students. This shift will entail equally significant shifts in teaching and assessment practises and the implications for both staff and students are discussed in this paper. We are especially concerned to identify the kind of support that may need to be offered to academics.

1 Introduction

Physics degrees in the UK and Ireland are accredited by the IOP as a way of recognising the educational achievements of graduates. Accreditation is the mechanism by which the IOP fulfils its obligation under its Royal Charter not only to maintain, but also to advance, standards in physics education. Professional competence is recognised through registration as a Chartered Physicist and an IOP accredited degree is the educational requirement for Chartered Physicist. In order to be registered as a Chartered Physicist, a member of the IOP must show education to the level of a Masters degree in physics, or equivalent through a combination of education and experience. In addition to the educational requirement, a member must also be able to demonstrate attainment in across five competences to a responsible level through appropriate professional practise (https://membership.iop.org/chartered-physicist-cphys).

Accreditation sets out minimum standards of skills and content knowledge that must be met by graduates. Therefore, a graduate from an accredited Bachelors degree

D. Sands (✉)
Independent Science Education Consultant, East Yorkshire, UK
e-mail: david.sands@physicseducationinternational.com

R. Henriegel
Institute of Physics, London, UK

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2023

J. Borg Marks and P. Galea (eds.), *Physics Teacher Education*,
Challenges in Physics Education,
https://doi.org/10.1007/978-3-031-44312-1_16

automatically meets in part the educational requirements for professional recognition. The requirements can be met fully either by further study within higher education or by appropriate professional development within the workplace. Within the UK, stand-alone, second-cycle Masters degrees comprising a minimum of 180 standard UK credits (designated CATS and equivalent to 90 ECTS) provide one route to achieve the requisite education level, but there also exist Integrated Masters (IM) degrees. Within these, students meet the educational outcomes of a Bachelors programme by the end of year 3, but, instead of graduating, go on to complete a fourth year of Masters level study.

Until recently, the IOP has not accredited stand-alone Masters degrees owing to the very wide variety of often specialised degrees on offer, but the accreditation scheme has been broadened to include Masters degrees offered by physics departments. By contrast, IM degrees have long been accredited alongside Bachelors degree programmes, as they provide for a complete coverage of the educational requirements: education to Masters level as well as the required physics concepts taught at Bachelors level.

As implied in the title of this paper, the accreditation criteria have been changed after the most recent review. The scheme is reviewed every five years as a matter of good governance and the last review set out to address some perceived shortcomings. The previous requirements for accreditation placed the emphasis on knowledge and therefore were quite prescriptive about what should be known by a graduate from a UK physics degree programme. Although skills were included, there was a sense that these should, rather than must, be taught and as a result, there was no clear requirement for a graduate to be able to demonstrate a minimum competence. Several consequences ensued. First, feedback from employers in various fora suggested that while graduates might be knowledgeable, they were not very skilful. Secondly, physics degrees themselves looked remarkably similar, as teaching the required content took most of the first two years of a Bachelors degree and often extended into the third. Thirdly, it became apparent that in many departments some topics in the Core were not taught to any depth but were simply included in a few lectures in order to ensure that the subject was not entirely absent from the curriculum. Fourthly, degrees which emphasised particular aspects of applied physics, for example to biology or the environment, found it difficult to meet the knowledge requirements and were effectively excluded from accreditation.

The solution to these difficulties was to shift the emphasis away from the programme to the graduate, from knowledge of particular content to competences, which are defined here as a combination of knowledge, skills and behaviours. This would address employers' concerns, allow departments to differentiate themselves from their competitors by freeing up space within the curriculum to develop both skills and knowledge, remove the need to address certain topics superficially, and allow applied physics degrees to be accredited by showing that graduates have developed the requisite competences. The implementation of these changes was interrupted by the outbreak of the COVID-19 pandemic, but the transition from the old scheme to the new has now begun. These criteria, and their impact on both academic staff and students, framed in terms of behaviours, will be described in this paper.

2 Accreditation Requirements

As described above, the previous accreditation scheme (Institute of Physics 2018) was very much focussed on the programme and specified knowledge across a broad range of topics. Called the Core of Physics, these consisted of,

- Mathematics for Physicists
- Mechanics and Relativity
- Quantum Physics
- Condensed Matter Physics
- Oscillations and Waves
- Electromagnetism
- Optics
- Thermodynamics and Statistical Physics

The detailed content to be taught under each of these headings is set out in a further list of topics. In some cases, for example in thermodynamics and statistical physics and quantum physics, the topics are broad enough to require further sub-division. Table 1 illustrates the knowledge hierarchy for quantum physics.

By contrast, the new criteria are much less prescriptive on knowledge and much stronger on skills requirements. The Core of Physics has been replaced by knowledge corresponding to the five fundamental areas set out in Sect. 3.2 of the 2019 QAA Benchmark statement (QAA 2019):

Table 1 The knowledge hierarchy for quantum physics within the IOP core of physics

Top level	2nd level	3rd level
Quantum physics	Background to quantum mechanics to include:	• Black body radiation • Photoelectric effect • Wave-particle duality • Heisenberg's uncertainty principle
	Schrödinger wave equation to include:	• Wave function and its interpretation • Standard solutions and quantum numbers to the level of the hydrogen atom • Tunnelling • First order time independent perturbation theory
	Atomic, nuclear and particle physics to include:	• Quantum structure and spectra of simple atoms • Nuclear masses and binding energies • Radioactive decay, fission and fusion • Pauli exclusion principle, fermions and bosons and elementary particles • Fundamental forces and the standard model

- electromagnetism,
- quantum and classical mechanics,
- statistical physics and thermodynamics,
- wave phenomena
- the properties of matter

Individual departments are free to set out how knowledge and understanding in these areas are developed throughout the degree programme. Compared with the Core, it is noticeable that both optics and condensed matter physics are absent. A department is free to choose whether to include either of these within their curriculum or not, but they are not required to be taught for accreditation. Conventional condensed matter physics, and in particular modern semiconductor physics and device technology, is an excellent example of the application of both quantum mechanics and electromagnetic theory to modern technology and could be used to help develop a detailed understanding of the principles of both. However, a department might wish instead to teach other things, for example, soft condensed matter, or perhaps omit condensed matter entirely in favour of other topics. Similarly, optics can be used to develop an understanding of both waves and electromagnetism, but could be omitted entirely. The flexibility that such a scheme affords should broaden the scope of physics degrees that can be accredited.

In essence, the requirement for a degree to be accredited has been shifted away from knowledge to a set of graduate attributes and as long as these attributes are developed, the kind of specialised knowledge beyond the five areas listed above taught to undergraduates is secondary. Central to these attributes is the idea that students should be able to demonstrate not just knowledge, but understanding. However understanding is defined, and there appears to be no succinct, universally accepted definition within the literature, a common theme relates to the ability to apply knowledge to unrehearsed situations. Qualitative reasoning would appear to be an essential aspect of this. It has been known for some time that students can demonstrate facility in mathematics and still possess a shaky grasp of concepts (McDermott 2001) so the fact of being able to solve complex mathematical problems is not in itself evidence of conceptual understanding. On the other hand, using concepts to develop qualitative arguments would suggest a sound understanding of the underlying physics.

The new accreditation criteria are set out in five principles and thirteen key expectations. The principles set out the expectations of the department and the university, such as the existence of robust quality assurance and enhancement processes and providing a positive and stimulating experience and an inclusive environment, and the key expectations set out the requirements of the programme as well as the graduate attributes. The programme requirements include such things as the provision of open-ended investigative work and the provision of training in a broad range of transferable skills. By way of example, four such expectations are given in Table 2.

The rationale behind key expectation 3 has already been described in relation to conceptual understanding. Key expectation 4 addresses a related issue, which is the connection between mathematics and physics. The disjunction between ability in mathematics and conceptual understanding (McDermott 2001) has already been

Table 2 Four key expectations from the new accreditation criteria

Key expectation	Detailed description
KE3	Students can demonstrate that they can apply their physics knowledge across topic boundaries and in unrehearsed contexts
KE4	Students can demonstrate the ability to use mathematics to model, describe and predict phenomena in the real world
KE8	Programmes provide an experience of the practical nature of physics and equip students with a range of practical skills necessary to plan, execute investigations and analyse data
KE12	Programmes must provide training in a broad range of transferable skills and their use should be demonstrated throughout the programme

discussed, but we do not yet have a complete model of mathematization in physics. In other words, despite years of work (Pospiech et al. 2019), the mental processes involved in translating between the physical and mathematical domains are yet to be elucidated. However, there is a growing consensus that translating from the physical to the mathematical at the beginning of the modelling process and from the mathematical to the physical at the end of the modelling process is crucial (Uhden et al. 2012; Sands 2021). Yet, these aspects of the modelling process are hardly, if ever, taught in traditional physics instruction [see Hestenes (1987), for example], where the emphasis is very much on mathematical development. Within the new accreditation criteria, they are regarded as skills to be developed and will require explicit instruction and opportunities for practise. In short, students are expected to develop an understanding that mathematical equations represent a physical reality and demonstrate the ability either to model some physical phenomena mathematically or at the very least understand the physical foundations and implications of mathematical models.

Key expectation 8 emphasises the importance of experimental skills, but is so worded as to allow students of theoretical physics to develop an appreciation of experimental physics while still developing investigative skills. The distinction between experimental and theoretical physics degree programmes is deliberate. Students on a programme of experimental physics are expected to develop their skills to the point where they could, in principle, undertake experimental work with minimal supervision. Whether that happens in practise in a Bachelors programme is another matter, but students in their final year of an Integrated Masters programme might be expected to work independently on their project to a great extent, in effect unsupervised for large periods, and so the final year of a bachelor's programme which precedes the Integrated Master's stage must prepare students for this eventuality. It is also a crucial aspect of employability. We have mentioned employers' concerns over the skills of new graduates and this reflects the belief that students entering the industry after graduation should be equipped with the skills necessary to undertake practical work with varying levels of supervision, depending on their environment. There is increasing evidence that scripted experiments do not develop experimental skills to a very high level, and environments in which students have to make decisions in open-ended investigations are much more effective (Etkina et al. 2021; Smith et al. 2020; Smith and Holmes 2021).

Key expectation 12 is largely self-explanatory. Transferable skills include the ability to communicate scientific information to a wide variety of audiences as well as group work. These are also important for employability as well as academic work. Not only must students be able to report on and defend a scientific investigation, by, for example, answering questions following a poster, oral, or written presentation, but they also need to be able to explain concepts and describe complex phenomena. The ability to work as part of a group or team is also important. Rarely in the modern world do people work in isolation. Crucially, the guidance accompanying the accreditation criteria states that, "these skills are taught, developed, built upon and assessed" (https://www.iop.org/sites/default/files/2022-09/IOP-Degree-Accreditation-Framework-July-2022.pdf).

Together, the five principles and thirteen key expectations are intended to ensure that students are presented with a stimulating, supportive and well-founded environment in which to develop knowledge and understanding of the five fundamental areas as well as a range of both transferable and physics-related skills appropriate to a twenty-first century professional physicist.

3 Impact of the Accreditation Criteria on Students and Academics

The new accreditation criteria point to a very different model of physics education compared with the previous criteria. It is probably fair to say that within the UK, and possibly much wider, much of physics education at undergraduate level is still focussed on the transmission of information by staff who regard research in the discipline as their primary career focus. That is not to say that such staff are not conscientious in their teaching, but that their teaching is likely to consist predominantly of traditional lectures. The contructivist approach, which posits that the learner has to construct his or her own knowledge in order to make meaning, is likely to be adopted by a minority of staff, if at all. Yet the constructivist view, with its emphasis on active methods of learning to enable to students to go beyond facts and to be able to construct meaning, underlies the new accreditation scheme. As described by Gerace and Beatty (Gerace and Beatty 2005), "Learning physics is more than just coming to understand the concepts of physics, however. It also entails learning how to think like a physicist: developing the *habits of mind* that allow one to make productive use of the knowledge base …. PER [Physics Education Research] has come to see learning as an active process of engaging in directed cognitive activity to construct useful knowledge structures while practicing skills and mental processes."

The IOP does not promote particular methods of teaching or forms of assessment. How students are encouraged to develop not only a deeper understanding but also the skills to learn independently is entirely a matter for the departments, but the requirement to provide evidence of such development means that students must be provided with the opportunity for such development throughout the degree programme. This implies that the majority of staff will have to embrace active learning in one form or another and adopt assessments that not only enable students to demonstrate their skills and achievements, but also encourage constructive behaviours. The conventional, unseen timed examination at the end of a module or academic year is limited in what it can assess. Questions might well contain unseen elements, but they have to be answerable within the time allotted. Questions that require more than a few minutes of thinking time are going to stretch a student's ability to complete a paper and truly unseen problems for which students have had little or no preparation are likely to be problematic.

The new accreditation criteria require programmes that will encourage desirable behaviours, such as seeking understanding, applying knowledge, a willingness to apply principles and self-learning, and discourage undesirable behaviours, such as focussing on knowledge, learning by rote and seeking the "correct" equation to solve a problem. However, changing students' behaviour is not simply a matter of changing pedagogy and expecting students to respond accordingly. Some students strongly resist active learning and in feedback suggest that they learn more from conventional, lecture-based instruction than from active learning even when the evidence from assessments points to the contrary (Deslauriers et al. 2019). The cause was attributed in Deslauriers et al. (2019) in part to the increased cognitive effort required by active learning and one answer is to intervene directly to address this misperception.

It is also quite likely that part of the reason for the perception that active learning is not as effective as conventional lecturing is due to a view of learning different from that of academic staff. Baxter Magolda (1992) has shown that many students at the start of their university studies view knowledge as absolute, either right or wrong, with the job of academic staff being to impart that knowledge and ensure that students have learned it. Learning in this sense comprises little more than committing to memory. Lectures are heavily biased towards delivering information, which is easily committed to memory. It is also easy to self-test this kind of learning by simply attempting to recall what has been memorized. Learning in an active environment, however, embodies the notion of transformation: a transformation from a state of low knowledge and limited ability to a state of greater knowledge and higher ability, as well as a transformation in behaviour. Appreciating just what has been learnt requires self-reflection as well as a comparison with the state before the transformation. From this perspective, it is perhaps not surprising that without appropriate guidance students do not appreciate the benefits of active learning.

Baxter Magolda's epistemological reflection model provides a good basis for looking at student behaviours. Baxter Magolda was working in a liberal arts college and followed a number of students through their studies, examining their assumptions and beliefs about knowledge and learning as they progressed from entry through to graduation. She noted four distinct phases of development, which she called ways of knowing. These are, Absolute Knowing, Transitional Knowing, Independent Knowing and Contextual Knowing. We focus here on Absolute Knowing as the likely starting point and a combination of Independent Knowing and Contextual Knowing as the desired end point of a Bachelors programme. Some aspects of Contextual Knowing, such as students and staff critique each other, might not be relevant, but students can be expected to go beyond Independent Knowing in order to demonstrate the competences outlined within the Key Expectations. The details of all three forms of knowing are described in more detail in Table 3.

It should be noted that Baxter Magolda's scheme is but one of a number of similar schemes describing personal epistemologies in the open literature. The majority of them describe similar outlooks and are developmental in the sense that a transition from a binary view of knowledge (right or wrong) to something far more nuanced is associated with intellectual development. Baxter Magolda's view of Transitional Knowing might well be influenced by the environment in which she worked, namely a liberal arts college. She described students in transition as sometimes seeing the relativity of knowledge whilst in other contexts regarding knowledge as absolute. The latter was especially associated with the sciences, where knowledge is often regarded as factual.

It is not clear, therefore, what Transitional Knowing looks like within a single science such as physics and for this reason this category is not included in Table 3. It is unlikely that the mixed modes of thinking observed by Baxter Magolda occur to

Table 3 The five domains of absolute, independent and contextual knowing (After Baxter Magolda, 1992)

Domain	Absolute knowing	Independent knowing	Contextual knowing
Role of learner	• Obtain knowledge from authority (instructor)	• Thinks for self • Shares views • Creates own perspective	• Exchanges and compares perspectives • Thinks through problems • Integrates and applies knowledge
Role of peers	• Share materials • Explain	• Share views • Source of knowledge	• Enhance learning via quality contributions
Role of instructor	• Communicate knowledge • Ensure that students understand	• Promotes independent thinking; exchange of opinions	• Promotes application of knowledge in context • Promotes evaluative discussion of context • Student and teacher critique each other
Evaluation & assessment	• To show instructor what has been learned	• Rewards independent thinking	• Accurately measures competence • Students and teacher work towards goal and measure progress
Nature of knowledge	• Certain or absolute	• Uncertain: everyone has beliefs	• Contextual: judge on the basis of evidence in context

any great extent, as scientific knowledge is factual, having been tested and re-tested systematically against evidence. However, knowledge may be incomplete and it may be that recognition of this and the corresponding implications trigger the transition to a more independent way of thinking. Partial knowledge implies the existence of beliefs. These should be evidence-based, but the corresponding knowledge will still be uncertain, as befits a belief. Such uncertainty is the hallmark of Independent Knowing and might well be one of the first steps in the transition away from Absolute Knowing. In addition, in ever more complex group interactions peers are also likely to play a role in shaping perceptions of learning. Peer instruction is well known as a way of teaching within first year physics, and this fits with the recognition that peers can share materials and explain. However, as peers, guided by an instructor, begin to contribute to the construction of meaning the idea of knowledge as absolute conveyed by an authority figure is likely to lose traction.

One of the key insights to emerge from Baxter Magolda's work is the role that assumptions play in students' approaches to learning. Students will only do with knowledge what their assumptions about that knowledge allow. Baxter Magolda was quite clear that, rather than teaching students study skills, it is better to change their assumptions. As discussed above, interactions with peers might well be an effective way of challenging those assumptions, but it has to be done carefully. For example, if students are in the state of Absolute Knowing and therefore regard their peers as having little or nothing to say beyond explaining facts, then presenting them with an open-ended problem and expecting a meaningful discussion is unlikely to be successful.

This brings us neatly to the role of academic staff in developing students' knowledge, skills and understanding. The preceding discussion has shown that students need to be active participants in their own learning. Among other things, they need to be able to apply knowledge to solve problems, express physical ideas mathematically, interpret mathematical formalisms, discuss concepts with their peers, design and execute experiments and report on and defend the outcomes of those experiments. Through such activities, students will not only be constructing their own knowledge but also restructuring existing knowledge to take into account new information and to resolve conflicts in their understanding. Academic staff have an important role to play in these processes. The traditional model of learning at university is based very much on the transmission of information, but in order to meet the outcomes of the new accreditation scheme staff will have to go beyond this: they will have to conduct activities that promote learning by doing.

Providing students with opportunities to do something rather than simply to listen requires a change from being a teacher as an authoritative source of knowledge to a facilitator of learning. As discussed by Neville (1999) this involves a considerable, and sometimes difficult, change in self-concept. According to Knowles, quoted by Neville (1999), it involves focussing on what is happening to the students rather than what the lecturer is doing. Knowles found himself, "functioning primarily as a procedural guide and only secondarily as a resource for content information". Therefore, the change to a guide from an authoritative figure could be difficult not only for those students who see academics as an authority, but also for staff who see themselves as an authoritative source of information. The challenge for academic staff is to decide not only on the activity and the kind of peer-to-peer interaction, but also the amount of supervision and guidance to be offered, as leaving students to construct their own knowledge and understanding with minimal guidance is not very effective as a method of facilitating learning (Kirschner et al. 2006).

In summary, we want both students and staff to change their behaviours in the classroom or lecture theatre. The behaviours of students will be determined not only by their assumptions about knowledge, but also by their environment and the expectations and behaviours of staff. If students are taught and assessed in ways that promote rote learning and recall, attempts to foster a deeper understanding will be undermined. In order for students to meet the outcomes set out in the Key Expectations, staff will have to teach in such a way as to promote thinking and reflection and this presents its own challenges. For staff more used to teaching the conventional, transmissionist way, this can represent in itself a significant, and perhaps difficult, change in behaviour.

4 Discussion and Conclusion

The new accreditation criteria currently being rolled out for physics degrees in the UK and Ireland represent a marked shift in emphasis away from a prescribed content to outcomes and the competences that students should acquire by graduation. In defining competences as a combination of knowledge, skills and behaviours, we have emphasized the impact of the new criteria in terms of behaviours and in particular moving students' behaviour away from unproductive habits aimed at memorization and recall of content knowledge towards understanding and application of knowledge. These changes require corresponding changes of behaviour among staff away from conventional transmission of knowledge towards a constructivist approach in which students are given the opportunity to develop a deep understanding of physics and its connections with mathematics. In effect, the development of competences in students requires the development of competences in staff to be able to teach and assess for understanding.

We have argued that in order to change students' behaviour their assumptions about knowledge must be challenged to allow productive behaviours to develop. This means developing shared meanings of important concepts, such as learning and understanding. It is also important to develop a common understanding of what is meant by the various types of skills mentioned in this paper, such as physics-specific, transferable, personal and inter-personal and employability skills.

We have discussed some of the challenges facing staff and in particular the need to support staff in developing approaches to teaching and assessing for understanding. Such support is currently being developed by the IOP. Feedback from the community on the new criteria suggests the strongest need lies in the requirement to develop skills, both physics-related and transferable. Specifically, support is needed in:

- Using varied assessments that allow students to demonstrate not only their knowledge, but also the ability to apply it;
- Running group exercises and team work, especially group exercises with increasingly complex peer interactions as students progress through the programme;
- Running open-ended experiments in the laboratory that will allow students to develop their practical skills through authentic investigations;
- Employability skills, including personal reflection and the ability to articulate which skills have been developed and how.

In order to change behaviour effectively, support will not just focus the "what and the how" as described in the preceding paragraph, but also the "why" as set out in the following questions:

- Why active learning?
- Why align assessments with educational goals?
- Why have students design their own experiments?
- Why have students construct mathematical models?
- What is guided learning and why is it effective?

A clear understanding of the educational advantages of different approaches to teaching will enable staff to choose not only which methods might be most effective in the context of their own institutions and degree programmes but also will determine in turn the kind of evidence required to demonstrate students' achievements in meeting the Key Expectations.

References

Baxter Magolda MB (1992) Knowing and reasoning in college: gender-related patterns in students' intellectual development. Jossey-Bass Publishing, San Francisco

Deslauriers L, McCarty LS, Miller K, Callaghan K, Kestin G (2019) Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom. PNAS 116(39):19251–19257. https://doi.org/10.1073/pnas.1821936116

Etkina E, Brookes DT, Planinsic G (2021) The Investigative Science Learning Environment (ISLE) approach to learning physics. J Phys: Conf Ser 1882:012001

Gerace WJ, Beatty ID (2005) Teaching versus learning: changing perspectives on problem solving in physics instruction: invited talk at the 9th common conference of the Cyprus physics association and greek physics association: developments and perspectives in physics--new technologies and teaching of science, Nicosia, Cyprus. https://doi.org/10.48550/arXiv.physics/0508131

Hestenes D (1987) Toward a modeling theory of physics instruction. Am J Phys 55:440–454

https://membership.iop.org/chartered-physicist-cphys

https://www.iop.org/sites/default/files/2022-09/IOP-Degree-Accreditation-Framework-July-2022.pdf

Institute of Physics (2018) The physics degree: graduate skills base and the core of physics. https://www.iop.org/sites/default/files/2019-10/the-physics-degree.pdf

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 41(2):75–86. https://doi.org/10.1207/s15326985ep4102_1

McDermott LC (2001) Oersted medal lecture 2001: Physics education research—the key to student learning. Am J Phys 69:1127. https://doi.org/10.1119/1.1389280.

Neville AJ (1999) The problem-based learning tutor: teacher? Facilitator? Evaluator? Med Teach 21(4):393–401

Pospiech G, Michelini M, Eylon BS (2019) Mathematics in physics education. Springer, Cham, Switzerland. ISBN: 978-3-030-04626-2

QAA (2019) Subject benchmark statement: physics, astronomy and astrophysics. https://www.qaa.ac.uk/docs/qaa/subject-benchmark-statements/subject-benchmark-statement-physics-astronomy-and-astrophysics.pdf

Sands D (2021) Modeling as sensemaking: towards a theory of modelling in physics education. Eur J Phys 42:064001

Smith EM, Holmes NG (2021) Best practice for instructional labs. Nat Phys 17:662–663

Smith EM, Stein MM, Walsh C, Holmes NG (2020) Direct measurement of the impact of teaching experimentation in physics labs. Phys Rev X 10:011029. https://doi.org/10.1103/PhysRevX.10.011029

Uhden O, Karam R, Pietrocola M, Pospiech G (2012) Modelling mathematical reasoning in physics education. Sci Educ 21:485–506. https://doi.org/10.1007/s11191-011-9396-6