Pre-service Physics Teacher Education at Primary and Secondary Levels

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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.

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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.

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