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Work Group 5 Position Paper: Strategies for Pre-service Physics Teacher Education

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Abstract. Pre-service physics teacher education is key in preparing prospective physics teachers to effectively support student learning and interest development alike. In order to do this, pre-service teachers must acquire, among other things, a profound teaching-oriented content knowledge and positive stance regarding teaching and motivation towards teaching. However, there are many more issues related to pre-service physics teacher education. In this paper, we report about some questions raised and answers proposed about this subject during the GIREP Malta 2020 Webinar Work Group 5 discussions.

1. Introduction

Research has shown that teachers' professional knowledge positively affects instructional quality and student learning [1, 2]. In particular, pre-service education of teachers is widely considered a crucial factor for securing quality of education [3], as it is supposed to shape future teachers' professional knowledge, providing them with tools and skills they need to meet the challenges related to their future career.

The starting point for an "effective" pre-service teacher training model should be the consideration that it cannot be limited to a set of simple ways of separately transmitting disciplinary and pedagogical/psychological knowledge. Rather, it should provide pre-service teachers with tools and methodologies for an "educational reconstruction" (e.g., [4]) of the disciplinary contents, adapting these tools and methodologies to the peculiarities of the contents. Furthermore, it should be necessary to take into account the problems of understanding, motivation and beliefs of students (and of teachers, see [5, 6]), and the results of research in cognitive sciences and in disciplinary teaching, which can provide significant contributions for the contextualization of teaching problems and suggestions for approaches to their resolution.

On the other hand, many papers on teacher education report that in almost all countries pre-service teachers bring to teacher education coursework a subject-matter understanding substantially different from the kind of conceptual understanding that they are supposed to develop in their future pupils. This has been shown, since a long time, in many fields of science education [7-10]. In physics in particular, it is well documented [11, 12] that the procedural understanding and the conceptual knowledge of physics that pre-service teachers typically build during their university physics courses are not adequate for teaching physics according to many proposed innovations involving changes in content, teaching in context, at different school and comprehension levels, didactical aspects and pedagogical methods and use of modern information and communication tools. Moreover, research shows that content knowledge is a necessary but insufficient condition for pre-service teachers. Once a minimum of content is learnt, more content knowledge (without pedagogical content knowledge, didactical reflections, action research and so on) does not provide better students' results.

All this points to the need to reshape the programs for pre-service physics teacher education, deepening the future physics teacher understanding and beliefs about teaching and learning. The main aim of these programs should be to help pre-service teachers to develop a suitable initial professional knowledge base, leading to an effective in-class application of modern pedagogical approaches based on innovative and research and evidence-based ways to teach physics and facilitate student learning.

It is well known from the research that to develop a suitable initial professional knowledge base, which is central for the adoption of a change in education towards a more research-based way of teaching (one that takes into account what students already know, 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 subject matter domain [13], activating a profound reflection on the actual conditions of effectiveness of such strategies in daily teaching practice [14, 15].

Therefore, to deploy a better model for the dissemination of best practices, the need to understand in more detail the relationships between the teachers' professional knowledge base and teaching practice in a specific disciplinary domain, clearly emerges.

In science education research, a consensus model for teacher professional knowledge and skill has been recently proposed in 2015 by Gess-Newsome [16] 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 [17, 18] and several scholars have contributed to our understanding of it (e.g., [19-22]). 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.

2. Work Group 5 discussions

With the previous considerations in mind, discussion in Work Group 5 during the GIREP Malta Webinar 2020 was developed in order to find possible answers to some questions (shown below) related to pre-service physics teacher education programmes and possible strategies for enhancing them:

1. What is an adequate format for pre-service physics teacher education?
2. What sort of content structure should be the base of a XXI century pre-service physics teacher?
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 detail is added to the previous questions in the following points:

1.
   - How do different routes taken worldwide to achieve the degree to become a professional teacher compare? (Academic degree in physics subjects, then pre-service teacher education vs. Academic degree in physics and physics education)
   - How can we achieve a balance between subject matter-oriented courses (physics education, science education, didactics, pedagogical content knowledge, ….) and general education courses?
   - How is the practicum incorporated in pre-service physics teacher education? (Observing lessons conducted by experienced teacher, creating lesson plans, teaching lessons, classroom management)

2.
- What are the basic ideas /concepts /models of physics pedagogical content knowledge for pre-service teachers?
- How can the physics content knowledge learnt at university be reconstructed for effective teaching?

3.
- What are the main activities to be included in a pre-service physics teacher education course?
- What role should pre-service teachers/students have in a physics teacher education course?
- What is the role of "Active Learning" in pre-service physics teacher education?
- What is the role of experimental/laboratory and modelling activities in pre-service physics teacher education?

4.
- What are the effective strategies to develop digital competences of pre-service physics teachers? (mastering digital tools, video, digital images, hardware and software for measuring, modeling, simulations, learning management systems, etc.)
- What are the challenges in pre-service physics teacher education programmes for implementing the methods and strategies needed for online teaching (distance learning)?

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

2.1 What is an adequate format for pre-service physics teacher education?

The routes taken worldwide to achieve the degree to become a professional teacher are quite different among the various countries. Generally, a specific academic degree (Physics, Mathematics, Engineering, Science) is required for become a secondary school teacher, but the routes to become a teacher and the subjects taught may be very different. There are countries where Physics is either taught alone or together with disciplines like Mathematics or Chemistry. In other countries Physics can be taught together with a secondary subject that can be far from being considered related to science, like History or Physical Education. Also, in some countries there is a specific degree for becoming a physics teacher while in others a master degree is required, after having obtained the science degree. Despite the diversity, many common issues emerged. Among them, some were emerging as cross-contextual and were discussed in some detail during the Work Group activities:

- there is a general lack of interest and motivation to become a physics teacher. As a consequence, in many countries there is a lack of physics teachers and/or the presence of physics teachers non-specialists in physics;
- content knowledge and pedagogical knowledge are considered separately and introduction to Pedagogical Content Knowledge construction during pre-service courses is not common;
- the role of mathematics in physics is relevant and many difficulties in learning physics can be also ascribed to that role and to the way mathematics is perceived by the future teachers;
- there is the need to introduce future teachers to cooperative forms of work, that can also be an important part of their future professional development.

The first issue emerged strongly from the discussion. It can probably be due also to low salary and lack of social support, recognition and respect towards the teachers' professional career. A common consequence is that in some countries there is a shortage of specialist physics teachers, so that it is possible to have teachers of Physics who graduated in Biology, Chemistry, Mathematics or other disciplines. This is clearly not an optimal situation, as the problem highlighted in the introduction, related to the teachers' procedural understanding of Physics, which may be inadequate for teaching the subject is obviously amplified, in those cases of physics teachers not specializing in the discipline, who studied Physics at the university only as a secondary subject.

Considerable discussion time was devoted to the second issues, trying to understand how is it possible to achieve, during pre-service teacher education programs, a balance and close interaction between subject matter-oriented courses and general education courses. It emerged that a critical analysis of the topics to be taught is needed from both the content and the pedagogical level, as research has clearly shown that a generic knowledge of educational strategies (pedagogical knowledge) and of the content (content knowledge) is not sufficient for teaching. As we said in the introduction, pre-service physics teachers need to study and experiment how particular pedagogical strategies and methods can be implemented in the specific physics domain. Reflection on the student learning difficulties and on the possible causes of these difficulties (strongly real-life validated common-sense knowledge, linguistic and conceptual knots, social aspects, etc.) must be activated, possibly by having these teachers participating actively in daily teaching practice, during apprenticeship activities.

Moreover, pre-service teachers need to reflect on the development of the ability of the students to ask questions, instead of simply repeating/declaring learned content. Physics must be linked to critical thinking. It is better to know what is not being understood rather than seemingly solving a problem without understanding the underlying concepts.

The third common issue was discussed, starting by the acknowledgement of the negative influence that “Math anxiety” can have in physics learning. Physics is often considered by the students as a difficult subject, also because a characterizing aspect of it is the mathematics-based description of physical laws and relationships. If this anxiety could be mitigated, Physics would probably be seen by students as being much easier. A proper pre-service physics teacher education program should take this issue into account, leading the pre-service teachers to modify the traditional approach to teaching Physics, that sees the subject first theoretically introduced (mainly by using mathematical language), and then resorts to experiments and demonstrations to confirm the theoretical previsions. An approach to physics teaching that reverts this order and focuses on conceptual physics understanding, starting from the observation of real-life situations and developing the physical sense of the world would probably obtain better learning results. While this approach can be proposed in a pre-service physics teacher education program, it is sometimes hard to actually materialise in several countries. One of the reasons being that graduate students often take their beliefs and understanding of physics based on their experience as students, to pre-service teacher preparation courses.. We all know that quite in many cases, university teaching is currently still based on the traditional lecture-based model (e.g., [23]) and on a logical learning flow that goes from theoretical considerations to specific applications, seen as “confirmation” of the theory. Today a shift from the traditional Theory-Confirmation paradigm in teaching Physics is recognized as necessary.

The fourth issue was also well presented during the discussion, highlighting that pre-service teacher education programs should contemplate periodic meetings among pre-service teachers, in some cases with the contribution of more experienced teachers, to share, discuss, compare and contrast their educative strategies. Watching and discussing videos of real-life teaching episodes was also perceived as an important strategy in pre-service education programs. Observation, deconstruction, participation to real lessons and discussion of real lesson plans is well recognized as a good way to make pre-service teachers aware of many students’ learning difficulties and learning knots that, if studied only theoretically, may not be perceived by the pre-service teachers as very relevant in effectively improving student learning.

It was noted that fora, coffee-hour meetings and other structures favouring teacher interaction can represent good opportunities to prevent and alleviate another issue raised in some pieces of the literature (e.g., [24]), i.e., the “teacher loneliness” during the various phases of her/his career. A teacher that can easily interact with colleagues, exchanging ideas and discussing and comparing pedagogical tools and approaches, can likely become more self-confident of her/ his efficacy as a teacher. This can help the teacher in becoming more aware of different learning tools that can help students, thus probably exploiting different student learning styles and attitudes.

2.2 What sort of content structure should be the base of a XXI century pre-service physics teacher education?

Discussion about the possible content structure for effective teacher education mainly took into account Shulman’s PCK construct and its components, as recognized by the several literature contributions to the subject developed in the last years. The currently accepted model of Teacher Professional Knowledge and Skill (TPK&S) [16] has four components, strictly interrelated:

1) Teachers' Professional Knowledge Base; 2) Topic-Specific Professional Knowledge; 3) Classroom Practice, and 4) Students' Learning Outcomes. As suggested by Gess-Newsome [16], teachers' professional knowledge base includes knowledge of assessment (how to design and use formative and summative assessments), pedagogy (e.g., instructional strategies, lesson plan design, etc.), content (academic content of the discipline), students (their cognitive and physical development, student differences) and curriculum (understanding the goals of curriculum, its structures). Topic-Specific Professional Knowledge is considered as the knowledge of a specific discipline from the perspective of favouring students' learning, including the knowledge of content representations and learning knots, student learning difficulties and content and discipline-related pedagogic strategies. This knowledge is generated by research or best practice (e.g., how to teach force and motion concepts, what are common students´ misconceptions, role of real-time experimentation, simulations, etc.). In this model, the pedagogical content knowledge itself is recognized as personal knowledge that results in everyday classroom practice in addition to the accumulated/shared knowledge for teaching that is the result of research (both evidence-based and research-based knowledge). The model involves students´ outcomes that plays an important role in affecting teachers´ topic-specific professional knowledge. The model also recognizes the existence of variables that can moderate the relationships between the four main components of TPK&S model. In fact, research has shown that teachers' beliefs, orientations about teaching and perceived self-efficacy can affect classroom practice [5, 25]. At the same time, student interest towards the discipline, prior knowledge, and self-efficacy perceptions are strong moderators of the relationships between classroom practice and students' outcomes.

However, while being a powerful framework to improve our understanding of how effective teachers enact their skills in their practice, the relationships among the TPK&S model components have still not been thoroughfully investigated. For instance, concerning Physics, many pieces of research focused on analysing the relationship between professional knowledge base and classroom practice (e.g., [19, 26]), but research studies about the relationships among components of the TPK&S model have been limited both in scope and sample size [27]. Taking into account the above-mentioned model, the pre-service teacher education is expected to develop strong knowledge and skill in the field of professional knowledge base, topic-specific professional knowledge and partially personalized pedagogical knowledge based on classroom practice. Nevertheless, it is a dynamic system and all the components are continuously developing during the teacher professional career and within in-service teacher training.

Another point discussed during the WG5 activities dealt with the way physics content knowledge learnt at university can be reconstructed for effective teaching. Various pieces of research in science education contributed in the last years to the body of knowledge on effective means of teaching and learning science. Among all the contributions, the Model of Educational Reconstruction proposed in 2012 by Duit at al. [4] has gained popularity among science education researchers. It provides a conception of science education research that has been considered relevant towards improving instructional practice and teacher professional development programs. A key point of the model is that both science subject matter issues and student learning needs and skills deserve equal attention in attempts to improve the quality of teaching and learning. Four major emphases are intimately connected in the model: (1) The close examination of science subject matter (including its main conceptual knots); (2) The deeper investigation into student and teacher perspectives regarding the chosen subject (including student prior knowledge, interests, self-efficacy perceptions, attitudes, and skills); (3) The careful planning, design and evaluation of learning environments (e.g., instructional materials, learning activities, teaching/learning sequences); (4) The interest that developmental or Design-Based research as an approach in Science Education has recently gained, showing how this latter aspect, previously related only to innovation, is today one of the important lines of both research and teacher education programmes.

A constructivist approach for the design of teaching/learning sequences aimed at facilitating students to evolve their prior knowledge toward a form of knowledge more resonant with the scientific one is at the basis of the Educational Reconstruction model.

2.3 What teaching and learning strategies can help to improve pre-service physics teacher education?

The issue of effectively shaping the main activities to be included in a pre-service physics teacher education course was also discussed during the WG5 activities. The first and most obvious answer to the need to build effective programs for pre-service education is to directly involve the pre-service teachers in a process of active development of their own professional knowledge. Research studies suggest that to develop suitable professional knowledge, teachers have to experiment how pedagogical strategies can be implemented in their specific subject matter domain [13], possibly by being directly involved in activity-based forms of professional development. Teachers must be engaged in an interactive process of innovation in teaching driven by reflection on practice, reflection on action and/or action research and the development of activity-based learning tools. Thus teachers can systematically and carefully examine their own educational practice, actively collaborating with the instructors, who are, hopefully, research experts in the teaching and learning of the discipline [28], also in the production and validation (during possible apprenticeship activities) of specific pedagogical tools and materials to be used in classroom activities. In such a way, the relevance of dimensions such as motivation, self-efficacy and beliefs (i.e. [5]) can be strengthened.

The pre-service teachers should work in a learner-centred environment in which all would actively and intentionally construct knowledge about the project topic:

i. asking questions and defining problems;
ii. planning and carrying out investigations by means of hands-on and minds-on laboratory activities aimed at collecting, analyzing and interpreting data;
iii. developing and using models to reflect, describe, explain;
iv. using Information and Communication Technologies (including current common technology like digital ones, sensors or even mobile phone apps), in laboratory and modelling activities.
v. comparing different explanations (from experts and non-experts), generalizing, building quality diagnosis and criteria-based comparisons, designing solutions;
vi. implementing models into simulations to understand how current technology tools can facilitate the students to actively construct their understanding of the world;
vii. engaging in an argument stemming from evidence;
viii. obtaining, evaluating, and communicating information

Reflective practice methods [14, 15] should be at the basis of the pre-service education program, by taking into account that all learning activities, and therefore also the ones enacted within the program, must be based on making sense of complexity during action, *reflection-in-action*, and on a second reflective domain, relevant to the objective of learning to teach, the *reflection-on-action*, to review the complex teaching/learning interaction by making sense of it. In that way, the pre-service teachers can think about their personal understanding and on the efforts one makes to learn, and so to possibly also understand their future students' difficulties.

2.4 How should teacher education use and promote digital competence to enhance both face-to-face and online teaching?

From what we have said previously, it is clear that pre-service physics teachers also need to develop digital competences for effective teaching. The final part of WG5 discussion was devoted to the use and promotion of pre-service teachers' digital competence to enhance both face-to-face and online teaching. Distance-teaching/learning and evaluation tools, video instruments, hardware and software for real-time measurement and analysis, modelling and simulation environments should be at least familiar to pre-service teachers. One must take into account that their future students will probably be already well skilled in the use of digital tools and possibly well-disposed to the use of those kind of tools, in the usual class practice. This calls for the introduction, in pre-service teacher education programmes, of courses for digital literacy also embedding these topics in general content courses.

The opportunities offered by the modern technological tools, that can be a bridge between teaching and effective learning, especially if their use in education is fostered during teacher education programmes, clearly emerged during the WG5 discussion. Particularly in these last times, plagued by the COVID-19 pandemic that has drastically reduced the possibility to conduct face-to-face pedagogical activities, online teaching should be considered as an opportunity to enhance learning. A reflection on strengths and weaknesses of teaching from a distance can offer an opportunity for teachers in pre-service education programs to reflect on how to engage students. This type of teaching can be very effective, by allowing students to “do physics” at home, with readily available devices, connecting physics to everyday experiences and allowing the students to “take the laboratory at home”. Examples are the use of mobile phone sensors, video trackers that enable the students to collect and process data. Moreover, simulations can be a reasonable alternative to real experiments, if it is not possible to conduct the experiments in the home environment. However, even since a long time, it has been known [29] that there are issues and challenges with distance teaching, like the need to maintain the level of attention in the students, hidden costs, misuse of technology and the attitudes of instructors, students, and administrators. Moreover, appropriate assessment methods that enable to collect relevant and proper information about the level of understanding needs to be designed and examined. The above-mentioned issues should be discussed during the pre-service education programme.

3. Conclusions

As a result of the discussions, we can conclude that there is no common model of pre-service teacher education across the participating countries. At the same time, it is not considered essential to develop one single model of pre-service physics teacher education, since there is a wide diversity of educational systems and different needs regarding teacher recruitment and training across the countries.

The routes to become a professional physics teacher may vary. Nevertheless, there are many common problems and challenges identified in this field that signal the direction that future research and action in the field could take. The common problems are related mainly with the lack of interest towards taking up a physics teacher career, the content and organization of pre-service physics teacher study programmes and achieving a good balance between the content and pedagogical content knowledge delivered during the study. There is also the question of the quality of teaching at different levels, including problems from kindergarten level (not a lot of presence of physics in early years' education) to university level (in many countries based on traditional lecture-based methods). For prospective physics teachers, in particular, the implementation of more interactive instructional methods and strategies would be strongly recommended. It is impossible to break the tradition and change classroom practice along schooling, unless future teachers do not themselves experiment different teaching and learning models.

Digital literacy of prospective teachers is considered an important issue with regard to pre-service teacher programmes. The importance of the use of digital technologies, already emphasised for several decades, is nowadays even more evident in relation to the COVID-19 situation. Problems with their use in distant teaching and learning can be seen in various areas, e.g., classroom management, learning by inquiry, assessment, etc. There are also many open questions on which technologies are appropriate and how to implement them effectively, in online education. Pre-service teacher education courses need to reflect on this, dynamically benefiting from the skills of pre-service teachers who belong to the young generation, with good technical skills and flexibility in this field.

Other aspects that we could not discuss but that are really important in teacher education in physics are issues related with identity, gender and inclusion. For instance, it is well known that there are a lot of problems involving girls in physics. Unfortunately, there is, in general, still little attentions given to these issues in many initial teacher education programmes. These aspects would surely need to be discussed in great detail to prepare future teachers to confront the challenges that are waiting for them in their career and professional development.

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