Preparing teachers in grades K-6 to help young pupils learn physics: toward a common research agenda

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Abstract. Standards documents envision that students in grades K-6 engage in developmentally appropriate yet substantive learning in physics and physical science. Students are expected to engage in the practices of the discipline, trying to develop – and experimentally defend – their own explanations of rich everyday phenomena. Teachers need special preparation to meet this challenge. Traditional preparation in lecture-based science university courses or courses that emphasize engaging demonstrations with little intellectual ballast are unlikely to yield the kind of rich experiential and rich discourse-based instructional environment for young pupils to thrive. In this GIREP Symposium, speakers introduced promising models for teacher preparation and enhancement and contribute to a discussion in search of a coherent research-based agenda for like-minded GIREP members.

1. Introduction
The symposium was the occasion of discussing four Pre-service (PPT) and In-service (IPT) Primary Teachers training research activities with common aims of improving teacher preparation at university levels. The value of this symposium and its main outcome is a picture of the different approaches and methodologies employed by the various research groups. In this sense, a first step in the direction of drawing a common research agenda consists in acknowledging and drawing a scenario of the approaches that result more effective and suitable for the preparation of grades K-6 teachers on a research basis. In the following we will synthetize the methodologies presented during the symposium. Though this list is not exhaustive, it is an important contribution toward a shared research.
2. First paper: “Development of Professional Competences of Prospective Primary Teachers on Fluids”, by M. Vidic, R. Maurizio and M. Michelini.

In this work, the PPT Education MES model integrate research based Metacultural, Experiential, and Situated formative experience during teacher preparation phase [1-4] and is focussed on the construction of a flexible Pedagogical Content Knowledge (PCK), based on Physics Education Research (PER). The theoretical framework adopted is the Model of Educational Reconstruction (MER) [5]. The following five activities, which are aimed at preparing PPTs for path planning an instructional unit and implementing it in class, characterise the MES model: 1) conceptual reconstruction of subject matter, 2) analysis of main conceptual difficulties of specific topic, 3) analysis of research-based educational proposals, 4) reflection on how main conceptual activities are dealt with in proposed instructional sequences, and 5) group discussion about activities, instruments and methods as suggested in the explored proposals. The personal involvement of PPTs in planning and analysing educational proposals for primary schools and practical classroom implementation of the developed proposals [1-4, 6] are the main characteristics of the chosen approach and of the present research. Resources for educational discussion during interactive lessons were research-based proposals on the same topic dealt with in class [6]. As for teaching strategies and methods, Inquiry-Based Learning (IBL) and Prediction, Experimentation, and Comparison (PEC) were chosen. Conceptual analysis of subject matter topics and corresponding goals proceeded in parallel with educational discussion [2, 5].

The overall research goal was the analysis of the role of the MES model in PPT professional development, with particular reference to the contribution of planning and implementing an educational path on a specific topic. In a previous work we study the role of the MES formative module offered to 89 PPT in the Physics Education course of 9cts analysing the educational proposals developed by PPTs by means of a simple standard Rubric (S1-S2) [7]. Here we study the role of the process of a successive detailed planning and implementing an Intervention Module in School (IMS) by 26/89 PPT, prepared and discussed with the course teacher (MM) and peers. The research questions (RQ) flowed from the overall goal.

RQ1) How do PPTs use basic concepts on fluids in planning their educational proposal for IMS?
RQ2) How do PPTs profit and transform the research-based educational proposals on fluids offered during their formative experience?
RQ3) How do PPTs collect and analyse data on the pupils’ learning process during the IMS?
RQ4) How do PPT reflect on their own learning process?

The MES model adopted for PPT Physics Education poses the challenge of integrating pedagogical and content knowledge by means of a research-based approach, while at the same time building professional competencies in Science Education. Different competencies are integrated in order to prepare PPTs to plan and implement learning pathways: reconstruction of fundamental concepts and knots of the topic, analysis of research-based proposals, PEC strategy and IBL methods, testing and selection of exploratory experiments, and critical discussion of a proposed sequence. Research-based activities combined with classroom practice complete the professional learning, enriched by data collection and relative discussion in the light of empirical evidence of children learning processes in a normal classroom where the planned IMS was implemented. Reflection of the personal learning on the whole formative experience was collected to identify explicit elements considered relevant by PPTs.

The analysis of PPTs’ reports reveals remarkable results on three main issues: 1) how PPTs use subject matter knowledge; 2) how PPTs reuse the educational paths on fluids studied during the MES, that is how they fit them into their own paths; 3) how they reuse teaching and laboratory activities they have experienced in MES formative model. In particular, data analysis shows that the approach – which is built around the discussion of research-based physics education proposals – plays a key role in building PPTs’ PCK and
facilitates the identification of those professional needs that are necessary to plan intervention modules for children.

Evidence shows that, during the meta-reflection phase of the overall experience, PPTs become more aware of their own learning process: the process of proposal planning, discussing and revising, produces a change of perspective in PPTs. Such transformation is apparent in the move from an information-based teaching to an exploratory, inquiry-based approach, where the need to include context in the picture contributes to formulating explanations and building interpretative models.

The in-class implementation of the planned proposals, as well as the related monitoring of children’s learning, contribute to meta-reflection by the PPTs. This type of professional preparation of the PPTs was considered by the authors of fundamental importance both for the direct experience with children and for the exposure to the teaching/learning process and practice with the class management (14/26).

From a teaching point of view, reflection on the phases leading to the final project fostered PPTs’ awareness of the importance of collecting children’s spontaneous ideas (6/26) as a starting point towards the construction of a flexible tool that outlines a significant path within which each child marks their own learning path.

The challenge to combine theory and practice was played out in the tasks of preparing tutorials and educational materials for children, which were in turn linked with the setting up of an effective learning environment and with the choice of a step-by-step approach to the development of concepts.

While engaged in the activities, PPTs activated a meta-reflection on their educational practices, on the relational dynamics with and among children, and on their ability to relate to pupils of different age groups; all these issues were in turn integrated with the informal learning resulting from the whole experience, which can be classified as an example of action research process.

The analysis of reports highlights how research-based education contributes to PPTs’ competence in eliciting children's spontaneous ideas through meaningful questions, collecting data on learning, analysing and then representing such data. Evidence shows that, during the meta-reflection phase, PPTs took ownership of their own learning process.

3. Second paper: “Inquiry-Based Learning and Teacher Preparation Program for Elementary School in Georgia”, by M. Kapanadze.

After the collapse of Soviet Union several educational reforms have been implemented in Georgia, but the country’s education system is still struggling to overcome the purely academic, subject matter structured, and teacher-centered paradigm in science and physics education [8].

The most substantial changes began in 2004 in the frame of the National Education Reform. The role and responsibility of the universities in the country is very important for the preparation of science teachers who will be equipped with the ability to integrate this new curriculum and conduct innovative studies of science in their classroom, as we know that teachers are key to success of any innovation [9].

Ilia State University (ISU) is one of Georgia’s leading universities in teacher education programs. After implementation of the SALiS (Student Active Learning in Science) project [10] new curriculum and science education courses for teacher education were designed. In-service science teacher programmes, offered by SALiS Centre are designed in the frame of different EU funded projects, such as PROFILES [11], Chain Reaction [12], LeAGUe [13], ARTIST [14]. Georgian science teachers are trained in modern teaching and learning technologies. They become familiar with IBSE, Action Research, and use of Low-cost approaches in science lessons. After these training programs Georgian teachers have developed their own inquiry-based science lessons modules and implemented these successfully with their students.

The paper presents one course from the new curricula for elementary level pre-service science teachers at ISU. The course is about integrated and IBL in science and its structure is special - Result Format.
Students prepare research projects as part of this course. To be able to better understand the impact of the new courses the following research question was posed:

RQ1) Does this course help the pre-service teachers to develop IBL skills?

This study has utilised a qualitative approach, with pre-post interviews conducted with the students, and observations during the implementation of their projects, conducted with accompanying annotation. Two examples of projects are outlined below. One group of students – pre-service teachers studied the role of the practical work and inquiry-based experiments for enhancing students’ motivation to learn science in the 3rd grade. The topic of the lesson module was Magnets and Magnetic Field. A second project prepared by another students’ group, investigated the role of university laboratory in enhancing pupils’ motivation to study science.

After the analysis of pre-post interviews, also observations it was clear, that students: improved classroom practice; increased knowledge of Inquiry-Based Science Education (IBSE); developed collaborative working skills and inquiry-based learning skills. Pre-service primary teachers have seen importance of IBSE for the learning objectives.

Different reports [15, 16] suggest, that IBSE might be a promising approach to enhance pupils’ motivation and their learning outcomes. In order to change science teaching and learning in the school system, it is clear that teachers must play a very important role if innovation – such as the implementation of IBSE – should take place in schools [17]. Our experience shows how important it is to develop student-centered approaches and conduct inquiry-based courses in pre-service teacher education training programs. Furthermore, we think that the form of the seminars and the lectures should be changed at the universities. Seminars should be designed, and lectures should be prepared to be led by a more student-centered instruction and to provide opportunity to be flexible on reflection of the pre-service teachers’ own beliefs and experiences. We think that the type of pre-service teachers’ practical experiences at school is very important for their education. We suggest also offering more practical and inquiry-based courses during the university teacher education program and for in-service teachers professional development courses. Here we are formulating the questions for further study - how well prepared are university science teacher educators for the new changes? Are they familiar with the new teaching methods and research in this field? It is evident to us that it is necessary to organize professional development courses in modern teaching and learning approaches for university science educators.

4. Third paper: “Scientific Practices Organized in Inquiry-based Sequences about Flotation for Pre-service Teacher Training” by R. Lopez-Gay, M. Martinez-Chico, M.R. Jimenez-Liso, and F.J. Castillo.

Considering the reform recommendations calling for students' practical and cognitive engagement in scientific practices, efforts should focus on the pre-service teachers’ competence enhancement to teach science accordingly. In our view, the Inquiry-Based approach can become a fundamental pillar for teacher training, if it offers opportunities to develop the following scientific practices: Express and discuss personal ideas in response to contextualized questions; Contrast the validity of these ideas through evidence [5].

This paper describes an attempt to lead PPTs to experience Model-Based Inquiry (MBI) sequences when they are learning by doing [6], and to reflect on the teaching-learning process, so that their self-confidence and self-efficiency, with the long-term goal of thus promoting the incorporation of scientific practices into their future classes in Primary school. The MBI sequences are structured around the following phases with greater or lesser autonomy according to the PPTs’ experience and knowledge on this teaching approach [18]: 1. Address a question that engages students, 2. Express ideas or hypotheses, 3. Plan and evaluate a design to obtain evidence of impact, 4. Collect and present data, 5. Obtain evidence and analyze it to confirm or refute initial ideas, 6. Obtain conclusions and communicate them (descriptive knowledge). 7. Construction of a model to explain and predict [19].
Our proposal for initial teacher training is organized around complementary sequences: A) sequences focused on scientific learning, in which science is learned by incorporating scientific practices, as well as other contents (didactics) of the following type of sequences that are implicitly developed that serve as a reference to teach while they are learning by doing (teachers as learners); B) sequences of didactic and epistemological learning, in which the previous experienced sequences are analyzed and justified, deepening in some concrete aspect, by making PPTs reflect on the learning process experienced (teachers as thinkers), which gives them criteria to analyze and transform other teaching proposals designs (teachers as modifiers/designers) [20].

Considering the previously mentioned aspects, we focus the PPTs training on inquiry because it allows a simple structure, recognizable, affordable... to analyze sequences, modify, design, and evaluate activity sequences [20]. In particular, the activities of two inquiry-based cycles on the construction and evaluation of a model on the flotation and sinking of objects, as well as some results related to the objectives of the proposal are presented.

The results obtained show an evolution in the knowledge PPTs perceive to have gained after experiencing the sequence, as well as an effect on their pedagogical knowledge as shown in two types of findings referred to their professional activity: the positive evolution in the PPTs’ priorities of the "relevant activities to learn science" throughout the course; and their preference for teaching closer to the Inquiry-based approach, expressed in their class journals. However, we are conscious this declarative knowledge and desire to do is only a first step, and there are many factors that are possibly more determinant of what their professional practice will ultimately be like. Therefore, further research is recommended, as we are doing through considering the evaluated aspects and instruments presented in the evaluation section. The results we are obtaining lead us to think that engaging PPTs in Inquiry Cycles supports appropriate development of understandings of science and scientific activity and helps them to learn how these teaching approaches work valuing their effectiveness.

5. Fourth paper: “How Feasible is to Integrate Nanoscience-Nanotechnology Content with Pedagogical Content Knowledge in a Primary Teachers’ Professional Development Course?” by A. Spyrtou, M. Chaitidou, L. Manou, P. Kariotoglou, and E. Hatzikraniotis.

The designing of professional courses aiming at the acquisition of teachers’ Nanoscience-Nanotechnology (NST) content knowledge as well as of PCK is considered crucial in order for teachers to reflect on their beliefs as learners and as teachers. Under this lens, in this paper a professional development course is presented. The course is depicted in figure 1 and combines the following five characteristics: (i) the introduction of NST content in an inquiry learning environment, (ii) the explicit introduction of PCK, teachers’ engagement in (iii) Lesson Planning as well as in (iv) Teaching Practice and (v) a continuous teachers’ collaborative reflection on their own experience in the course [21]. We hypothesized that the integration of these characteristics could significantly contribute to teachers’ knowledge about NST content as well as it could enhance their own practice with inquiry learning activities such as analyzing data, modelling etc. We also assumed that teachers could develop their own critical thinking concerning educational issues such as to be open-minded towards the incorporation of modern science fields (e.g. NST) in grades K-6 [22]. The duration of the course was 16 lessons (48 hours).
Figure 1. Characteristics of a professional development course for teachers in Grades K-6

The professional development course was designed on the basis of the three PCK components. In particular, content knowledge includes concepts, phenomena and applications of NST related to NST Big Ideas [23]: landmark objects of nanoscale (virus, DNA) (Big Idea: Size and Scale), lotus and gecko effects (Big Idea: Size dependent properties), water nanofiltration (Big Idea: Science, Technology, Society), models (Big Idea: Models and Simulations). Pedagogy refers to the knowledge of teaching methods that we implemented for approaching this content, namely inquiry teaching methods (e.g. modeling), the Jigsaw method, out of school inquiry activities. Context knowledge involves the description of the educational material that is required for the NST content negotiation: a variety of representations (e.g. video simulations), several materials in order teachers to study lotus and gecko effect (e.g. superhydrophobic wooden surfaces, scratch strips), etc. PCK components were analyzed under the lens of NST content. Specifically, teachers with researchers’ support collaborated in order to become aware of these components as well as to share their reflections about the educational impact of each one, e.g. how useful is to teach models and modeling to primary students in order to help them approach the lotus effect. The collaborative reflection also was focused on their lesson planning and teaching practice. Specifically, having the feeling of interdependence, teachers planned and taught NST content to 5th-6th grade students.

We aim to answer the following research questions:

RQ1) How did the teachers’ conceptions on the term “Nanoscience-Nanotechnology” change after the course?

RQ2) How did the teachers’ conceptions on inquiry teaching-learning change after the course?

RQ3) What characteristics of the course do teachers think that could support changes to their own teaching practice?

Two sources of input were used for the evaluation of the course, namely (a) a questionnaire that measured teachers’ knowledge about NST content and about inquiry teaching-learning, and (b) an interview regarding the five course characteristics. The participants were 13 IPTs.

Prior to the implementation most of the content responses revealed that IPTs owned an incoherent view about NST. After the implementation, all of the participants expressed an informed view for at least one of the NST Big Ideas. Teachers’ conceptions of inquiry teaching-learning were enhanced mainly to modelling and the Jig Saw method, namely two aspects of pedagogy component that were not recognized in the prior measurement. Concerning the 3rd question, results revealed that nearly all the teachers: (a) focused on the newness of the NST field which they estimated as very interesting and feasible for introducing it in K-6 grades, (b) advocated the inquiry process of modeling as a pedagogy method for understanding complex science contents as NST, and (c) acknowledged the explicit introduction of PCK as a main factor for improving their lesson planning.
6. Concluding remarks.
The following threads run through the four contributions. There is a common sense that primary teachers need to experience the type of high-quality instruction, including instruction around cutting-edge scientific and technological concepts, in which they will be expected to engage as practicing teachers. This instruction needs to offer opportunities to come to understand the subject matter through the use of scientific practices, and be able to elicit, recognize, and build upon pupils’ ideas via research-based instructional sequences. Research projects should be an integral part of teacher preparation. Reflection on their own intellectual journey is indispensable, as is providing agency to primary teachers to express their own sense of self-efficacy around teaching the material learned in their professional education. Professional development of teacher educators is absolutely necessary to achieve the promise of Inquiry-based instruction in the schools. A common research agenda that targets pieces of the complex endeavor that is teacher education needs to be developed and pursued by researchers and teacher educators alike in different countries.

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