Exploring pre-service primary teachers' progression towards inquiry-based science learning

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Abstract

Background: An in-depth understanding of pre-service primary teachers' progression towards teaching science through inquiry is critical for improving teacher education programmes and, ultimately, improving the quality of science teaching and learning in the classroom.
Purpose: This study set out to describe and analyse the progression of pre-service primary teachers' learning during an initial teacher education course on how to teach science through inquiry. There was a specific focus on the progression of learning in the area of curriculum content as a component of pedagogical content knowledge (PCK).
Method: The sample consisted of 347 pre-service primary teachers grouped into 92 teams. As part of their pre-service training, they were designing science teaching proposals as part of the course on teaching science through inquiry. An analysis was conducted to explore the content of the designs created by these teams, both at the beginning and end of the course. Data were analysed qualitatively, using an interpretative approach informed by grounded theory.
Findings: The analysis identified that most of the teachers progressed in their learning throughout the course, although only 14 of the teams progressed in all categories. It was possible through the analysis to determine intermediate levels of learning, between the starting level and the highest level of PCK. The analysis also indicated that the change paths of each team were very different.
Discussion and Conclusions: Our study suggested that it was possible to analyse the professional learning and knowledge of the pre-service primary teachers in terms of progression in their learning of how to teach science through inquiry. Identifying progression in learning is complex and nuanced. However, we believe that this endeavour is an important underpinning research activity in order to support improvement in initial teacher education in primary science.

Keywords: initial teacher education; progression; pedagogical content knowledge (PCK); primary science teaching and learning; science curriculum content; inquiry-based science

Introduction

An important focus for research in science teaching and learning is the investigation of how teachers' pedagogical content knowledge (PCK) progresses when they participate in teacher education courses (Schneider and Plasman 2011 & Talanquer, 2014). An understanding of pre-service teachers' initial knowledge and how their learning about science teaching evolves is critical for improving teacher education programmes (Crawford & Capps, 2016). A general consensus on the relevance and worth of inquiry-based science education (IBSE) (NRC, 2012; Pedaste et al., 2015, Romero, 2017) is well established. In such student-centred teaching, students have an active role and the teaching facilitates learning through diverse means, including activity-driven, discovery, project-based science or inquiry approaches (Friedrichsen, Van Driel & Abell, 2011). However, it is important to recognise that future teachers of primary science may have preconceptions stemming from a teacher-centred rather than a student-centred orientation (Cheng et al., 2009; Pilitsis & Duncan, 2012; Bryan, 2013), where science teaching may, in contrast, be conceptualised as the direct transmission of science (Friedrichsen, Van Driel & Abell, 2011).

An important component of PCK is the curriculum content one aims to teach, as this aspect constitutes a key reference in decision-making regarding the planning and subsequent implementation of the teaching (Parcerisa, 2005). Despite its relevance, though, more attention needs to be paid in terms of what teachers learn about curriculum content during the teacher education processes. One of the few significant examples available in this regard is a piece of research by Schneider and Plassman (2011). They conducted a review of studies that examined PCK at different points during the teaching career, including pre-service, new, continuing, and leader teacher career phases and that formulated possible learning progressions. Such work highlights the importance of initial teacher education including the teaching and learning of *content* as an essential element of professional knowledge.

In previous research, we conducted a preliminary study of PCK progression in learning, with small samples of 3 to 5 teams of pre-service teachers (Martín del Pozo, Porlán & Rivero, 2011a). In that study, we detected a progression from a science teaching orientation based on the transmission of knowledge by the teacher, to a more student-based orientation. However, inquiry-based science teaching approaches were not reached. In current research, we are exploring the learning of a large sample of pre-service primary teachers. The pre-service teachers were working in teams as part of a course to learn to teach science in primary education through inquiry-based science teaching. In particular, our interest is in investigating different components of PCK: instructional strategies, children' understanding of science, assessment, and school science content. In this article, we focus on our analysis of the pre-service teachers' progression in learning with regard to the content of the school science curriculum.

Background

Pedagogical content knowledge (PCK) and science teacher education

The precise characterization of the professional knowledge needed to teach science is still debated in the literature. However, PCK has been broadly defined, since the late 1980s, as a genuine and differentiated form of knowledge which teachers use when they plan and teach, and which allows them to be distinguished from other professionals in relation to education (Nilsson, 2008; Van Driel & Berry, 2012; Nilsson & Loughran 2012; Gess-Newsome, 2015). It is knowledge that must be constructed through the enrichment from and interaction with other types of knowledge: (1) disciplinary knowledge linked to the subject matter to be taught (in our case, Natural Sciences) and Education Sciences (Pedagogy, Psychology, and so forth), (2) knowledge gained from experience and linked to the teaching-learning processes in specific contexts, and (3) meta-disciplinary knowledge that provides an epistemological, ontological and ideological perspective on science and science education. Crawford & Capps (2016, p. 19) summed it up as follows:

> […] teachers need to have a deep and integrated knowledge of foundational science concepts and principles, scientific practices, nature of science (NOS), and pedagogy, as well as take a metacognitive stance towards their teaching, in order to expertly engage their students in learning about scientific practices, including use of logic and critical thinking.

The PCK model in Magnusson, Krajcik & Borko (1999) has acted as a reference in numerous science education studies. Broadly, this model groups some of the aspects mentioned above and suggests that the components constituting PCK are: (1) *knowledge of the science curriculum* (which includes the different national standards of the contents that children are to learn); (2) the *understanding of the students* (the ideas the children have about science topics to be taught, learning difficulties, and so forth); (3) *teaching strategies* (which include knowledge about teaching activities and methods, and (4) *assessment of science learning* and (5) *orientations to science teaching*, considering that it includes the knowledge of teachers about the educational goals, the nature of the science and the scientific research and the general focuses of science teaching. Further, the model described by Gess-Newsome (2015) redefines PCK and places in a new organizational scheme in relation to the rest of the teaching knowledge. It distinguishes the Teacher Professional Knowledge Bases (TPKB) in general terms (including, among others, knowledge of the subject matter and pedagogical knowledge), a Topic Specific Professional Knowledge (TSPK) that manifests an integration of the base knowledge in relation to specific teaching topics, and a Personal PCK for the teacher, that is articulated and manifests itself solely in the action of teaching. It emphasizes that they are all linked together and are influenced by: the beliefs the teacher has, their goals in teaching science, and the students' results. Although we recognize the importance of these three perspectives, in this study we take, as our focus, topic-specific PCK. This perspective may be observed in what the pre-service teachers say and in their teaching plans: in general, it may be relatively easily recorded (Gess-Newsome, 2015).

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Inquiry-based science education

As mentioned above, an inquiry-based science education (IBSE) approach is broadly held to be the best way to further the teaching and learning of science. Romero (2017) analysed the results of three extensive, systematic reviews of the relation between research-based teaching and the students' learning results. The work suggests that inquiry leads to better learning, both conceptually as well as in terms of research skills and that the results are better if the inquiries are guided by a teacher rather than left open.

Although many interpretations of IBSE are evident, common features are: the creation of an environment where the students ask themselves questions and obtain data; the importance of motivation based on highly active role of the student as protagonist, and the importance of the teacher adopting the role of "guide" and "facilitator" in the inquiry (Couso, 2014). From our point of view, we believe that IBSE must also be coherent with four central suppositions: a) a vision of science as processes to construct models to explain reality, and not as discovery of the laws of nature; b) a socio-constructivistic vision of learning; c) recognition of the importance of metacognitive and regulation processes in learning; and d) a view of the school science goals linked to development of a participative, critical citizenship. In that sense, we identify with the reference framework for IBSE defined by Pedaste et al. (2015). These authors reviewed 32 articles, finding over 100 different terms for the different phases of inquiry. After a process of comparison and reorganization, they defined 5 phases that interact together and allow diverse applications according to the content, the context and the emergencies of the actual process: Orientation (including processes to stimulate curiosity and to formulate problems to investigate); Conceptualization (including promoting the formulation of hypotheses and/or questions related to such problems); Investigation (including planning investigations, data collection, analysis and building new knowledge); Conclusion (including comparing new knowledge with the investigation hypotheses or questions; and Discussion (including communication of the conclusions to colleagues and teachers, and meta-reflection about the process followed). Debate, communication and reflection, although emphasized in the final phase, are considered to be continuous processes that provide feedback to the students in their learning of high-level content.

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Purpose of study

As we noted above, our study set out to investigate the progression of pre-service primary teachers' PCK in terms of science content. This was investigated whilst the pre-service teachers were designing science teaching proposals, at the beginning and end of the teacher education course. The central research question of this study was: How does the knowledge of prospective teachers change in relation to school science content when they participate in a course to learn how to teach science? Specifically, we wanted to determine: (a) What criteria do they use to select the content?; (b) What types of content do they propose?, and (c) How do they present the content to primary education children?

Methodology

Ethical considerations

In carrying out the research, we carefully followed the guidelines suggested by the Ethical Guidelines for Educational Research (2018), the AERA Code of Ethics (2011) and the Spanish legislation that regulates the protection of personal data (Organic Law 15/1999, of December 13). We obtained informed and voluntary consent from the five teacher trainers and the students who participated in this study (AAA, 2012). We informed potential participants of the importance of their participation, what they had to do and what would happen to the information provided by them. They were given the opportunity of withdrawing when they deemed appropriate. In order to maintain the anonymity and confidentiality of all participants, we used pseudonyms in the reporting and carefully chose information units that did not contain identifying data.

The research context

The training course which was the context for our research was developed within the framework of a subject called Didactics of Experimental Sciences. This forms part of the Degree of Primary Education Teacher at the University of Seville. The training programme adopts a research approach to the problems of professional practice (including determining what characteristics the subject has, what science to teach and with what methodology, how to take into account the students' ideas, and what and how to evaluate). It engages with the contrast between the ideas and experiences of future teachers, innovative teaching practices and more general theoretical reflection. It is a ninety-hour course, which takes place within one academic year and includes 3 hours of class per week. The course takes place during the students' second year of study.

When teachers are initially being trained, the development of PCK is not an easy and immediate process. As Abell (2008, p.11) points out: 'Learning to teach sciences does not consist in acquiring a number of tricks based on a set of general pedagogical strategies, but rather developing a complex, contextualized set of knowledge to apply it to specific problems of the practice.' Therefore, in the training course we developed, we approach problems such as the content that is to be taught/learned in relation to a particular science topic, the methodology to be used, what to do with the children' ideas, and assessment issues (purpose, what and how), around which the construction and improvement of PCK is organized (Etherington, 2011; Borhan, 2014).

In terms of school science content, it is evident that pre-service primary teachers at the beginning of their training may be likely to adopt an approach aligned with a *teacher-based orientation* (also called traditional or transmissive). In selecting content, such pre-service teachers may take neither the children nor context into account, but rather the scientific concepts that are considered to be important and that appear as topics in the children' textbooks. This approach is usually very common among pre-service primary teachers, and therefore constitutes the majority *Initial level* at the beginning of the training course (Bryan, 2013, Rivero, Martín del Pozo, Solís, Azcárate & Porlán, 2017b). At the opposite extreme, coinciding with a *student-based orientation* (specifically with IBSE), content takes the form of problems to be investigated by children that are relevant to understanding and critical intervention by children in their environment (Ezquerra, Hamed & Martín del Pozo, 2017a). Thus, such content is selected based on criteria such as scientific relevance, meaningfulness for the student, functionality in the everyday context and its adequacy to the goals pursued. Here, content often shows a balance of the conceptual, the procedural, and the attitudinal, as all those dimensions form part of scientific knowledge and are necessary for development of inquiry processes. As teacher educators, this is our *Reference level* on science teaching courses. In Table 1, both orientations are summed up, constituting the system of input categories for our study with its focus on science content.

[insert Table 1 here]

Comentado [A3]: This will be Table 1 Categories of analysis

We now describe he components of the initial training course for learning to teach science. At the beginning of the course, the nature of science and scientific research was analysed. Throughout this work, the trainers aimed to carry out various types of team activities. Specifically, they guided pre-service teachers in terms of on how to work in groups. At this stage, the components of the team in each activity were constantly changing. After this point, the teams, now organized according to their own choice and established rather than changing, completed a Likert-type questionnaire to reflect on the professional problems mentioned above (see further, Hamed, Rivero & Martín del Pozo, R., 2016; Ezquerra, Hamed & Martín del Pozo, 2017a; López-Lozano, Solis & Azcárate, 2018). This instrument was also applied at the end of the course to characterize the global trend of individual student change based on the training proposal (Ezquerra, Hamed & Martín del Pozo, 2017a).

At the next stage, the students began to design a plan to teach a content of the area of Nature Sciences that they were interested in (initial design). This was an open document, without defined guidelines, which they prepared, without restrictions, taking into account their initial knowledge and experience. The content of the course was then discussed, with the discussion organized around curricular problems such as: What content do I teach? How do I teach it ? How do I take into account the ideas of the students? And how do I evaluate learning? Guided by the trainer and using various resources of interest (educational legislation, innovative curricular materials and contributions of educational research) the future teachers were encouraged to reflect deeply. After this process, the pre-service teachers were asked to complete a Reflection

Script, which, unlike the designs, was a structured document around a set of open questions that must be answered by the teams, through negotiation and discussion processes. Its purpose was to encourage students to express, in synthesis, their new knowledge about the professional problems they had worked on. In addition, they were asked to reflect and justify if they wished to make changes to their first proposed plan, where appropriate, giving rise to a second version of their teaching plan.

The pre-service teachers then worked with audiovisuals recorded in innovative classrooms that reflected a science education based on student research (Ezquerra, Blázquez & Martín del Pozo, 2010; Ezquerra, Rodríguez & Rivero, 2012). The reflection on and discussion about the video was addressed using a new reflection guide. Three types of audio-visual documents were used: a) statements by innovative teachers with practical experience; b) examples of types of classroom activities consistent with inquiry-based science teaching; and c) complete sequences demonstrating primary school children doing inquiry activities. Based on this, the teams produced the *final design* of their teaching proposal, which was to be compared with the first two. The presentation of this final proposal formed an element of motivation and also learning. At the end, the pre-service teachers completed the initial questionnaire again, and the teams were interviewed, in order to assess their learning and the whole training process. The stages of this training course are presented in Figure 1.

[Insert Figure 1 here]

Comentado [A4]: This will be Figure 1
Structure of the initial training course for learning to teach science

Participants

The course described above was taught by five trainers in the area of science, in the Faculty of Education at the University of Seville (Spain). Participants were 347 students who were in the 2nd year of their Primary Education Degree course. Their ages ranged from 18 to 25; most (70%) were women. They had completed secondary school studies in a range of different specialisms, including Science, Humanities, Technology and Art. The previous courses they had taken in the Faculty of Education had been based on general aspects of Psychology, Pedagogy, and the Sociology of Education. None of them had, at this point, carried out any teaching practice in primary schools. The five classes each had from 45 to 80 students. They were organized into a total of 92 teams (15 to 22 teams per class), each with 3-5 components. In these courses, it is usual for the pre-service teachers to work in groups, which is why the design of the teaching proposals was the result of team work rather than individual work.

Data collection and analysis

In this article, we focus on our analysis of the content designs prepared by each of the 92 teams at the beginning and the end of the course. The intermediate design was not analysed, since it only represented a partial reflection on their initial proposals and it did not really provide information on the process of change that we wanted to observe. For the analysis, three categories were selected: content selection criteria, type of content and presentation of content to the children. For each of these, two *levels* were established, according to whether a *traditional orientation* (Initial level) or an *inquiry-based teaching model* was adopted (Reference level) (see Table 1). We anticipated that our analysis would identify *intermediate levels* that would reflect an intermediate stage of learning by the course participants.

A qualitative analysis (Cohen, Manion, and Morrison. 2018) of the content of the two designs was carried out, using a grounded theory approach (Charmaz, 2014). The process included adjustment and operation procedures. The adjustment was related to the generation of conceptual categories from the data. Data that shared the same characteristics were grouped into the same category and level and were assigned a code that indicated the concept to which they belong. Accordingly, the procedure was as follows:

- *The significant information units* used in the two designs of each of the 92 teams were identified. This selection was carried out according to the meaningfulness rather than the accuracy of the linguistic expressions.
- The information units were classified into one of the three categories of analysis (Content selection criteria, Type of content and Presentation of the content to the students) with one of the levels envisaged (Initial / Reference). In cases where units did not fit into either of the levels envisaged, new intermediate levels were established.
- When we considered a new level in a category, we reviewed the internal coherence of it all.

Throughout this process of data analysis, the information was repeatedly reviewed, with the objective of discriminating, corroborating and strengthening the significant segments. To facilitate the organisation of the data, we used ATLAS.ti v8 as our tool. As a final stage, we used triangulation among researchers to check the reliability of observations and counteract the bias that may come from the vision of a single person. To this end, each category was analyzed by a researcher. Subsequently, and independently, another two researchers each checked 25% of the coded units (that is, 50% of the first analysis was checked). An initial rate of concordance of between 70% and 80% (depending on the categories) was detected. The discrepancies were evaluated by the third researcher and, in case of not coming to agreement, the majority option was chosen, thereby achieving a final concordance exceeding 90 % in all the categories.

Findings

In order to reflect the progression from the beginning to the end of the course, selected findings from our analysis are presented below in three sections: (1) Levels of PCK detected at the beginning and the end of the course; (2) The change in the teams' designs; and (3) a profile of the teams' progression. Where relevant, anonymised quotations are included from the data.

Levels of PCK detected at the beginning and the end of the course

In terms of *Content Selection*, in their initial design, most of the teams (71.7%) selected the contents of the discipline (Physics, Biology, etc.) that they considered basic and that appear in primary education children's textbooks. That is, they were at the Initial level that we anticipated. For instance, Team 10 proposed:

The universe. The Milky Way. The solar system. Rocky (Earth) and gaseous planets. Earth movements: rotation and translation. The day and the night. The seasons of the year. The eclipses.

In this initial design, two intermediate levels were also detected, both with incomplete characteristics of the Initial and the Reference levels. In this initial design, most of students were deemed to be at the Intermediate level 1, which was characterized as considering the discipline as the source of the content, according to the textbooks (similar to Initial Level). However, on this level, there is also a certain personal and/or social functionality included. For example, this is illustrated by Team 65, initial design:

The theme we have chosen for our teaching proposal is The Senses. It is a very important topic for children's lives, we believe that students should know about this topic and should use this knowledge in their daily lives.

In the final design, most of the teams opted clearly for a selection of content more suited to the children (Intermediate level 2). This Intermediate level 2 was characterized as considering the discipline, the children's ideas or the social function as some important criteria for selecting the contents. For example, Team 29 proposed:

> Activity 1: Assembly among all children so they can discuss what they know about animals (20 minutes). Once we have been able to verify what they know, we use the knowledge they already have for the explanation of the topic (which are the vertebrate animals and which the invertebrates).

We did not detect designs in which, in addition to extending the selection criteria, a meta-cognitive perspective was adopted. Lastly in this category, we noted that a considerable percentage of teams remained at the Initial level.

In terms of *Types of Content*, most of the teams formulated content that was purely conceptual in their initial design. As noted above, this is characteristic of the initial level anticipated. For example, Team 39 proposed:

> The human body.
> Outside, the parts and functions. Head: mouth, eyes, nose, ears. Trunk: Chest, belly button, waist. Limbs: arms (shoulders, elbow, hands and fingers), legs (hip, kneeling and feet), skin, hair and body hair. Differences between men and women.
> Inside, the parts and functions. Skeleton and musculature. The digestive, respiratory, circulatory, excretory, reproductive systems.
> The senses, the parts and functions. Vision, Ear, Taste, Smell and Touch.

However, in the final design, Intermediate level 2 was found to be the majority level. This is characterized by a clear relationship between the conceptual content, procedures and attitudes. At this Intermediate level 2, no specific justification appeared with the content proposed and how this helped to achieve the ends intended; this element differentiates it from the Reference level. For example, Team 91, Final Design is illustrative:

- Recognize and interpret the sensations perceived by the senses.
- Observe and explore through the senses the environment in which the children are immersed.
- Educate the children so that they understand that anyone who does not have all the senses may still be capable of living the same as they do.
- Recognize good habits in the care of the senses.

In terms of the *Presentation of school contents,* our findings indicated that, in the initial design, most of the teams proposed a list of topics which was in line with a traditional approach (Initial level). In this initial design, two intermediate levels were also detected. The Intermediate level 1 was characterized for considering a list of contents (like in the Initial level) but endeavouring to be more attractive to the pupils; that is, the formulation differed from a mere list of content. For example, Team 2 designed the following:

What do we understand by universe? Planets. The Earth (Web pages and videos that support the explanation). Types of stars. The Sun, Satellites, photos of the phases of the Moon… Excursion to the Planetarium. Making a model of the solar system.

In the final design, the Intermediate level 2 designs were in the majority: the content was presented in the form of questions or work projects. An apt example here is Team 29, Final Design:

The first thing we will do will be to present the theme that we are going to talk about. We will not use a textbook for this, but rather we will arrive in class and begin to eat an apple … we will ask a number of questions, such as, "Hey, what happens with the apple when we eat it?" in order to start a debate between all the children.

With the problems or projects proposed at the beginning of the theme, or in the different sub-sections of the theme, the teachers aimed for the content to be taught to make sense to their students. However, none of the teams repeatedly used the problems throughout the process to favour the content becoming prepared as the result of that investigation or negotiation.

In summary, our analysis identified that, at the beginning of the training course, most of the teams selected the basic concepts of the discipline and presented them as a list of concepts with no relation between them and without proposing other types of contents. This type of design is typical of a traditional orientation (Initial level). However, we also detected teams that made a more attractive presentation of the themes and included some procedures or attitudes, but without renouncing the continuation of listing concepts. We have characterized those proposals as Intermediate level 1. Nonetheless, in the final design, most began to take other criteria into account when selecting the content: primarily, children' interest and ideas, while also including content in relation to the scientific attitudes and procedures and including these in their proposed problems or projects. We characterized these proposals as Intermediate level 2. Table 2 presents the intermediate levels identified between the Initial and Reference levels.

[Insert Table 2]

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Table 2
Analysis of the Initial and Final designs

Team change in each category

The levels achieved in the designs prepared at the beginning and the end of the training course provided us with an impression of the overall change across the teams, in each of the categories that we studied. Specifically, in the *Selection of Content* category, 34 teams continued to select the content, at the end of the academic year, from the information in the children' textbooks only. The rest of the teams progressed to a certain functionality for the children (intermediate level 1) or took into account their ideas and interests or functionality for daily life (intermediate level 2). In the *Type of Content* category, most of the teams progressed in their designs, including in the content of a conceptual, procedural and attitudinal nature (intermediate level 2). Thirdly, in the category called *Presentation of the content to the children,* 59 teams progressed in their designs, from different starting points up to the formulation of questions or projects, while bearing the children very much in mind (intermediate level 2). Nonetheless, 33 teams continued to maintain the approaches that they had manifested at the beginning of the course; of these, 18 teams continued to propose a list of concepts in their final design.

In summary, most of the teams progressed in all the categories from a traditional orientation to an intermediate level which was, to a greater or lesser degree, near to the inquiry-based orientation. The best progress was detected in the category *Types of content*; however, in the *Criteria of the selection of content* category, there was greater balance, with 34 teams remaining at the Initial level of traditional orientation.

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Types of general progressions

If we take into account the changes experienced by each team at the beginning and end of the course in the three categories, different profiles can be obtained. For this, we consider that both the Initial level and the level that we call intermediate level 1 correspond to a traditional orientation, whereas intermediate level 2 may be regarded as a focus of transition towards the inquiry-based teaching model which we consider to be the reference level. The PCK level of the designs was designated according to the number of categories obtained at a given level. Therefore: *low PCK* describes a situation with all the categories at the Initial level or intermediate level 1; *medium PCK* equates to some categories at the Initial level or intermediate level 1; *high PCK* refers to all categories at intermediate level; finally, in *excellent PCK*, all the categories or all except one are at the reference level). Additionally, the type of progression was established according to the number of categories whose level might have changed. Starting from a position where *there is no* progression in any category, a *weak* progression was identified if one category had changed, a *considerable* progression if two categories had changed or a *strong* progression was identified if two or the three categories had progressed from the initial to the final design.

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In all, we identified 14 teams with a high level of final PCK who had progressed strongly or very well. For example, in their initial design, team 8 selected Nutrition as a topic. They commented, "since we consider that children should have a good command of the concepts so that they can have a good variety of food..." and suggested explaining a list of concepts to the children and then doing the related activities. However, as shown in Table 3, in their final design this team proposed content of different types.

[Insert Table 3 here]

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Table 3
A final design in the category of type of content (Nutrition teaching; Team 8 final design)

This content was selected after analysing the ideas that the children had put forward. They also decided to ask the children questions about the lunch they had the day before: *What are the main types of foods? What properties do foods have? How much of each food can we have? What is a healthy diet based on? Where do foods come from?*

On the other hand, the 8 teams with a *low level* of PCK, a traditional orientation, did not progress in any of the categories. For example, *team 43* undertook an initial design about *renewable energies* where they considered explaining the concepts and then carrying out activities from the textbook, all of which they did without referring at all to the ideas or interests of the children. In this team's final design, the questionnaire of prior ideas was similar to a memory-type exam on the renewable energies, as in the initial design, to explain the content and carry out activities.

Overall, by the end of the course, our analysis indicated that the majority of the teams (70 of the 92), had a PCK identified as medium. This meant that their progression was weak; change consisted in adding to the conceptual contents of the initial design, content about procedures and attitudes or considering the ideas and interests of the children in a very diverse manner. For example, in their initial design, team 6 selected the conceptual contents of the textbook on *Reproduction* and decided to *"conduct a brainstorm about what it is they understand reproduction to be."* After this, the teacher would explain the concept, they would carry out activities to recall what was explained and then watch a video as a summary. In their final design, this team added procedures and attitudes to the concepts selected.

Discussion

Our analysis of the initial design identified that most of the pre-service teachers embarked on their teacher training in the sciences with approaches near to a traditional teaching model, as has been previously observed (Cheng et al., 2009; Pilitsis and Duncan, 2012; Bryan, 2013; Schneider and Plasman (2011)). Underlying this is the notion that school content is a simplification of scientific concepts, and, therefore, that school content is not conditioned by factors such as children, context, socio-environmental problems, etc. A not insignificant number of teams were still at this Initial level at the end of the course. This may suggest that a powerful influence is the model of teaching that the pre-service teachers have themselves experienced during their schooling: they then reproduce it when having to make their own proposals to teach sciences (Bryan, 2013). Another possibility, noted by Friedrichsen, Van Driel and Abell (2011) in their review of studies on the progression of the PCK of the "science curriculum" components, is that teachers are initially unsure of what science themes are most appropriate for the children, and their organization of the content is inflexible so that they have to resort to the curricular materials (in our country, mainly the children's textbooks). Nonetheless, it is interesting to note that, in our study, this was not the same for all categories, as in the category we called *Types of Content*, some teams did include procedures and attitudes, more or less related to each other, in the initial design.

In the final designs, a marked evolution was detected in all the categories towards *contents more adapted to the student*, although without attaining inquiry-based science teaching (i.e. our Reference level).

What, then, does the necessary change require on the part of the pre-service teachers? Our analysis suggests that it necessitates a depth of change in conceptualisation and approach. Put another way, it requires conceiving content as the result of an *integration and recompilation* of knowledge deriving from diverse sources: scientific disciplines and their history and epistemology, scientific practices, the study of children's ideas, didactic analyses of school content, etc.), according to the goals in scientific education. As pointed out by other studies (e.g. Binns and Popp, 2013), the design of an inquiry-based science teaching model involves a deep change in the tasks of teachers and children, which is not easy to foster in one training course alone. One important challenge is precisely the conceptions held by pre-service teachers about science, research, teaching and learning (Haener and Sambal-Saul, 2004; Cheng et al., 2009).

However, it is important to note that the course we analysed produced changes in some aspects of PCK. The inclusion of procedures and attitudes in the contents to be taught appeared to be easier for the teams to learn than selecting content. It seemed difficult, though, for the teams to change the manner in which they presented content; equally, no team appeared able to formulate classroom problems that really act as an articulating axis around which to gradually build up the theme content or formulate classroom problems that were completely meaningful for the children. Nonetheless, 14 teams seem to be on the road to achieving this in their final designs. Such findings resonate with other studies (Fortas and Alonzo 2010; Pilitsis and Duncan 2012).

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Although we have reported on the main types of changes we identified, it is also interesting to reflect upon the diversity of types of changes experienced by the teams (depending on what their level was at the beginning of the course, their level at the end of the course and the category to which we referred). This highlights the need for the individual pre-service teachers to receive more precise feedback on their own progressions in the training processes. In their analysis, Arias and Davies (2017) attribute the differences found to the differences in the antecedents in knowledge and experience. Such diversity has led us to define different profiles and detect weak, considerable and strong progressions in the context of the course we analysed. Whilst 9 teams evidenced strong progression, more teams (35) evidenced weak progression, which could indicate the need to revise the course. The lack of progression evidenced in 25 teams in our study connects with the interesting findings of a study undertaken by Martinez-Chico, Jiménez and Lopez-Gay (2015), in which one third of the groups did not change after an initial training course on teaching science by investigation. As noted by Pilitsis and Duncan (2012), pre-service teachers' resistance to the change could also be a reflection of a lack of confidence: for example, the pre-service teachers may feel perhaps under confident that that the new approach will be more successful than what they already know to encourage better scientific learning for the children.

Limitations

Although the number of participants is high for a qualitative study, it must be borne in mind that all participants were from the same university, so the results have a clear relationship to this particular context: generalisation is not intended from this in-depth, qualitative analysis. It is also important to note that the findings were the result of the analysis of teaching designs and not from knowledge in action. These aspects must be taken into account when evaluating the findings: nonetheless, we believe that the insights generated from the analysis may be helpful for those educators involved in designing teacher education courses for pre-service primary teachers in the area of science.

Conclusions and implications

We suggest two principal conclusions from our analysis. Firstly, our study suggests that it is possible and potentially helpful to analyse the professional learning and knowledge of the pre-service teachers in terms of progression. Indeed, the levels formulated previously (Initial level and reference level), together with the new levels that we identified from the data (intermediate levels 1 and 2) have enabled us to further our understanding of the pre-service teachers' progression and the evolution of their learning. Secondly, we were able to observe that the change of knowledge of content gained by the pre-service teachers was gradual and diverse. It was gradual in the sense that no strong or radical changes were detected: in fact, no group reached the stage of considering the content as relevant problems to be investigated with the children; the balance of change was considerable (25 teams did not change their approaches). It was diverse because a large quantity of types of progression was detected. This means that, from a relatively homogenous initial situation, changes occurred in quantity (number of categories where they experience changes) and in quality (depth or relevance of the change). Moreover, the evolution came about in different ways in the different categories: they were of greater reach in the types of content category and of lesser reach in the other two categories. All the above allowed us to detect points of inflection in the process of teaching content being designed by future teachers. Moreover, it also demonstrates the challenges in achieving high level change in the initial teacher education.

Reflecting on our findings allows us to point to some implications for initial teacher education. Firstly, we suggest that teacher education programmes should create learning opportunities adapted to the learning that is really experienced by the teachers, in order to understand and support the knowledge progression of teachers undergoing initial training (Berry, Depaepe and van Driel, 2016). Moreover, we suggest that PCK progression should be a continuous process that commences at the initial teacher education stage, and continues with teaching practice and ongoing learning. In that sense, it would be interesting to explore the aspects that should be optimally focussed on at each stage of professional development in order to best support and improve the processes. Secondly, we believe that the training on the subject-matter knowledge should focus on aspects which pre-service teachers find more complex to learn and that are relevant to producing considerable progress in their PCK. In our case, for each of the categories that we analysed, these are:

(1) Facilitating the use of different sources of information for selecting content;

(2) Relating the different types of content and reflecting on the goals of scientific education to overcome the disconnect between conceptual content and content relating to scientific attitudes and procedures, and

(3) Formulating possible classroom problems and analysing their potential possibility of being investigated with the children.

Thirdly, as teacher educators, we highlight that, to optimize the learning of the pre-service teachers, it is important for the educators to be actively involved with the pre-service teacher teams, creating a climate of support so that the prospective teachers can explain their ideas continuously, while discussing possible improvements in their particular teaching proposals. In this way, we believe that the research endeavour we have described in this article represents an important underpinning research activity to support improvement in initial teacher education in primary science.

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