Designing a Course for Enhancing Prospective Teachers' Inquiry Competence

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Introduction

Inquiry, which refers to "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (NRC 1996: 23), is at the core of scientific endeavor. Numerous research reports (e.g., Abd-El-Khalick et al. 2004, Bartos and Lederman 2014, Capps et al. 2012) indicated that learners can similarly benefit from this approach through their engagement in learning activities centered on inquiry, and the resulting outcome is the development of inquiry learning. Inquiry learning is considered as an approach to learning that entails "a process of exploring the natural or material world, and that leads to asking questions, making discoveries, and rigorously testing those discoveries in the search for new understanding" (NRC 2000: 2). The key for a successful design and implementation of science instructional settings through which learners will be scaffolded in developing inquiry skills is the *teacher*, given that teachers are considered to be the "linchpin" in any effort to change science education across nations (NRC 2012).

Consequently, reform documents in science education have underlined the increasing importance of preparing teachers, who will play key roles in guiding students through cognitive activities centered on inquiry (NRC 2000). Davis et al. (2006) indicated that to design and enact science instruction centered on inquiry, teachers must have strong understandings of inquiry and abilities to teach inquiry. Similarly, the National Research Council stressed that "for students to understand inquiry and use it to learn science, their teachers need to be well-versed in inquiry and inquiry based methods" (2000: 87).

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Despite this persistent call, evidence from the literature revealed that a vast majority of teachers have unsophisticated understandings of inquiry and do not routinely adopt inquiry-based instruction within their practices due to a number of systemic and other barriers (Crawford 2000, 2007; Davis et al. 2006; Kazempour and Amirshokoohi 2014; Saad and BouJaoude 2012). Consequently, the key to overcome this gap is to invest on teachers' professional development (PD) both at pre- and in-service level. A critical challenge that emerges is to identify the key features that PD programs should entail in order to succeed in changing teachers' epistemic knowledge of the nature of scientific inquiry, helping teachers appreciate the impact of inquiry-based learning to students' scientific literacy, and assisting them in understanding how to design inquiry-oriented instruction in their classrooms (Capps et al. 2012), and consequently influencing the development of their pedagogical content knowledge for scientific inquiry (Davis and Kracjick 2005).

Additionally, it is equally important to identify the role of teachers within such a program in order to maximize their professional expertise on teaching science through inquiry. Prior research (e.g., Clarke and Hollingsworth 2002, Kazempour and Amirshokoohi 2014) indicates that positioning teachers in the role of *active learners* rather than as information gatherers and letting them experience themselves the same learning journeys that their students are expected to follow could be beneficial for their professional development; this role might result in teachers' construction of meaningful knowledge about inquiry and skills for inquiry teaching (Loucks-Horsley et al. 1998). A second role that is important for teachers to encounter during their participation in a PD program is the role of *thinkers* of both the learning experiences gained through the inquiry hands-on activities and the underlying design principles of the curriculum materials they engaged with as learners. Theoretical readings, class discussions, and other reflective activities may facilitate this role of teachers, as they allow themselves to reflect on their developing understandings, enhance their knowledge about certain aspects of inquiry-based learning, and can shed light on prior established misconceptions about inquiry and science in general (Akerson et al. 2007). Lastly, given that reflective practice, which refers to the capacity to reflect on action that leads in engagement in a process of continuous learning (Schön 1983), can be a beneficial form of teachers' professional development (Ferraro 2000). Hence, a third role that is considered essential for teachers to follow during a PD program is that of *reflective practitioner*. This role is facilitated through allowing teachers to implement curriculum materials they developed or received within the context of a PD program into their own practice, make necessary adjustments to their teaching according to situations occurred at a particular time, collect evidence to evaluate and reflect on the effectiveness of their teaching, and bring reports of their field experiences to the course and analyze teaching strategies with their mentors and colleagues.

Purpose and Research Question

We present the structure of a PD program through which we aimed at impacting teachers' development of inquiry competence, namely, *inquiry skills*, *views and definitions of inquiry*, and *pedagogical content knowledge (PCK) for teaching science as inquiry*. Our approach draws on the constructs of constructivist learning (Driver et al. 1994) and situated cognition (Brown and Campione 1990). It also builds upon nine critical features[1] of effective inquiry PD suggested by Capps et al. (2012) and follows the recommendations for positioning teachers as learners (Phase 1), thinkers (Phase 2), and reflective practitioners (Phase 3) within the context of a PD program. The development of the curriculum materials incorporated within the course was grounded on the inquiry-based learning framework suggested by Pedaste et al. (2015).

The research question that we aimed to address was: How did teachers' (i) development of inquiry skills, (ii) views and definitions of inquiry, and (iii) PCK for teaching science as inquiry change along the course? Specifically, what learning outcomes did teachers gain during participating in each of the three consecutive phases of the PD program?

Methodology

The participants were 72 preservice elementary teachers who attended a science method course in Cyprus, within which the PD program was implemented. During the previous semester, all teachers attended a content course that made use of the Physics by Inquiry curriculum (McDermott 1996), whereas none of them taught science during their school practicum.

The PD course, taught by two university instructors and three graduate assistants, was organized into twelve 1.5-hour sessions and split in three phases. During Phase 1, a curriculum titled "Boiling and Peeling Eggs" was implemented, through which the teachers (groups of four) engaged in multiple inquiry cycles to answer "How to make perfect hard boiled eggs that are easy to peel?" Specifically, the teachers as *learners* defined the problem that merited solution; identified variables that might affect the boiling and peeling of eggs; formulated investigative questions and hypotheses; designed and performed experiments; collected, analyzed, and interpreted data; drew conclusions; and presented their findings in posters. During Phase 2, the teachers as *thinkers* were asked to study the curriculum they previously worked with to identify the phases of inquiry and their interconnections, in order to inductively formulate the underpinnings of the inquiry-based framework that guided the design of the curriculum. Next, the inquiry-based framework was intro-

[1]All nine critical features are presented in the Discussion section in relation to how they were addressed in the design and implementation of the PD program of the present study.

duced, and the teachers compared their perceived frameworks with the original one. Finally, during Phase 3, the teachers were assigned the role of *reflective practitioners* and were asked to design lesson plans and curriculum materials on a particular topic that they would use to engage an elementary student in inquiry-based activities. Throughout the meeting with their student, the teachers maintained reflective journals to record their student's inquiry-based learning progress, and all phases of inquiry were reported on a poster that was presented during a *science fair* organized in collaboration with the teachers and a local school. At the end of the course, the teachers made presentations of their science fair projects, shared their reflections and lessons learned with their peers, and received feedback from the instructors and peers.

We collected multiple forms of data: (a) *teachers' written definitions of inquiry*, as documented in questionnaires administered during the first, the seventh, and the last course meeting; (b) *reflective diaries*, in which teachers were asked to document their evolving understanding of inquiry-based learning (used as means for capturing their PCK for scientific inquiry); (c) *pre- and post-assessment of teachers' inquiry skills*; (d) *science fair project work*; and (e) *end-of-course individual interviews*.

An open coding scheme refined through the use of the constant comparative method (Glaser and Strauss 1967) was followed for answering study's research question. Specifically, teachers' responses on the various data collection instruments were classified along a three-level inquiry advancement scheme, namely, *novice inquiry*, *basic inquiry*, and *advanced inquiry*. Novice inquiry pertains to teachers' responses that revealed the presence of naïve ideas and misconceptions about inquiry. The second category (basic inquiry) reflected the presence of a limited number of ideas that point to informed understandings about inquiry combined with instances of naïve ideas, whereas the third category (advanced inquiry) evinced the presence of ideas consisted with informed understandings about inquiry.

Findings

The findings are presented in Table 1 and are discussed in the subsequent three subsections in relation to teachers' inquiry competence development along the three phases of the PD program. Representative examples are also included within each subsection as evidence of how we reached these results.

Inquiry Skills

The findings revealed that in the beginning of the course, the level of teachers' acquisition inquiry skills was at a moderate level (79%, 82% – basic inquiry – see Table 1). With regard to teachers' identification of experimental flaw skill, the majority of teachers' responses indicated that they failed to identify all experimental

Table 1 Percentage of teachers' inquiry competence classification across three levels of inquiry (naïve, basic, advanced) during each phase of the PD program

Phases of the PD															
	Phase 1: Teachers as learners			Phase 2: Teachers as thinkers						Phase 3: Teachers as reflective practitioners			Final assessment (4 weeks after the end of the course)		
	Pre			Post/pre			Post/pre			Post					
	N[a]	B[b]	A[c]	N[a]	B[b]	A[c]	N[a]	B[b]	A[c]	N[a]	B[b]	A[c]	N[a]	B[b]	A[c]
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Percentage of teachers' inquiry competence classification across three levels of inquiry															
Assessment of															
1. Inquiry skills															
1.1.Application of the control of variables skill-data interpretation	5	79	16	0	8	92	x[d]	X	x	0	4	96	0	3	97
1.2.Identification of experimental flaws – revision of experimental design	9	82	9	0	10	90	x	X	x	0	6	94	0	3	97
2. Definition of scientific inquiry	87	13	0	12	58	30	2	26	72	0	13	87	0	4	96
3. PCK for teaching science as inquiry															
3.1.Understanding of the instructional strategies and tools for supporting inquiry	96	4	0	33	67	0	31	56	13	11	12	87	5	7	88
3.2. Knowledge of children's understandings and misunderstandings associated with inquiry	98	2	0	91	9	0	88	12	0	0	31	69	1	8	91
3.3. Knowledge of appropriate curriculum for inquiry	75	25	0	35	62	3	11	25	74	1	11	88	0	4	96
3.4. Knowledge of assessment techniques for inquiry	84	16	0	15	79	6	15	78	7	2	8	90	0	4	96

[a]Novice inquiry: presence of naïve ideas and misconceptions
[b]Basic inquiry: presence of a limited number of ideas that point to informed understandings about inquiry combined with some instances of naïve ideas
[c]Advanced inquiry: presence of ideas consistent with informed understandings about inquiry
[d]No administration of assessment tasks

flaws in a given experimental design. We present below a task that was administered to evaluate this specific inquiry skill followed by a representative quote from a teacher's response to document this finding:

> Marina conducted an experiment to test if the material a hammer nail is made of affects its rusting time when placed inside a liquid. She used three test tubes, three different hammer nails and two types of liquids. In the first tube she put an iron hammer nail and water. In the second tube she put a cuprum hammer nail and vinegar. In the third tube, she put a steel hammer nail, vinegar and water. Then, she left them in the kitchen for a week. At the end of the week, she observed that only the iron nail rusted. Therefore, she concluded that water affects the rusting of a metal pin in a better way than the vinegar. Do you agree with Marina's conclusion? Explain the reasoning behind your response. (Adapted from Constantinou et al. 2004)

A representative response that documents the majority of teachers' failure to identify all experimental flaws and thus their classification in the basic inquiry level is as follows:

> I don't agree with Marina's conclusion, because she should have put the same type of liquid in each tube in order to find out if the type of the material of a hammer nail affects its rusting when placed inside a liquid. (Teacher #14)

The abovementioned response indicates that this particular teacher identified only the type of liquid as the variable that should have been kept constant in the given experimental design and failed to identify other variables (e.g., the volume of the liquid in each tube, the size and material of each tube, etc.) that should have been kept constant. In addition, the teacher did not notice that the conclusion derived from the experimental design is irrelevant to the investigative question being researched (i.e., the investigative question pertains to the type of material of the hammer nail, whereas the conclusion focuses on the type of the liquid).

At the end of Phase 1, teachers made a significant shift in terms of the development of their inquiry skills (90% and 92% in advanced inquiry level), which was slightly increased by the end of the course (97% in advanced inquiry level, see Table 1). Almost all teachers were able to identify all experimental flaws in the given experimental design and proposed revisions of the experimental design in order to perform a controlled experiment to answer the investigative question under study. Teachers' slight inquiry skills improvement by end of the course might be attributed to the teaching experience they gained during working with their students for the science fair project, since they had to help their students develop inquiry skills themselves through the curriculum materials and the assessment tasks they developed.

Definition of Scientific Inquiry

At the beginning of the course, all teachers held uninformed views of inquiry and teaching science as inquiry (87% – novice inquiry – see Table 1). A representative quote with regard to the definition of inquiry-based learning, provided by a teacher at the beginning of the course and categorized in the cluster of naïve inquiry, is as follows:

> Inquiry is a learning situation during which students and teacher interact, discuss, and experiment with an appropriate problem and at the end they reach a mutual response. (Teacher #43)

Their definitions of inquiry were continually changed and improved throughout the course, since they progressed from 0% of advanced inquiry at the beginning of the course to 30% at the end of Phase 1, 72% at end of Phase 2, 87% at the end of Phase 3, and 96% at the final assessment which was performed 4 weeks after the end of the course. The following is a representative example of a comprehensive definition of inquiry (clustered as advanced inquiry) provided by teacher #43 at the end of the course:

> Inquiry is a process, similar to the one scientists follow in their daily work, though which a learner engages with a problem and performs several actions for solving the problem. Inquiry involves defining the problem of interest, making some research on getting insight on the concepts that relate to the problem, formulating a question and generating a hypothesis based on the question, designing a controlled experiment to answer the question, collecting and interpreting data, and drawing conclusions in relation to the initial question. The process is not a linear one, since one can follow different paths depending on the type of problem, the conceptualization of the problem, etc., and you can always go back to further investigate your question or formulate and test new research questions. (Teacher #43)

PCK for Teaching Science as Inquiry

Teachers' PCK for teaching science as inquiry was found to be significantly enhanced only after the end of Phase 3, since at the end of Phases 1 and 2, the majority of teachers' PCK was clustered as either naïve or basic inquiry. For instance, with regard to the aspect "Knowledge of assessment techniques for inquiry" prior to the course, a teacher provided the following response:

> During the first lesson with electric circuits, I would ask students to form groups of four and then I would give them a wire, a light bulb and a battery and I would challenge them to find a way to make the bulb to lit. Hence, I would be able to observe their reactions, if they are able to collaborate with each other, and with appropriate guidance I would keep notes if they can learn something new by themselves. (Teacher #66)

At the end of the course, teachers' *knowledge of assessment techniques for inquiry* was significantly increased (96% – advanced inquiry – see Table 1). An indicative quote from a response by teacher #66 is provided below:

> I would ask students to describe what they should do if they wanted to learn whether the sun is essential for plants to growth. In scaffolding their work, I would present 6 different pictures that varied in the type of the plant, the size of the pot, the presence/absence of sun, and the amount of water that is added in each pot, and I would ask them to choose which two they should choose in answering the posed question. (Teacher #66)

Similarly, teachers' *knowledge of appropriate curriculum for inquiry* was significantly improved. The following extracts from a teacher's lesson plans provided at the beginning and end of the course, through a task that sought to evaluate teachers' knowledge of appropriate curriculum for inquiry, are particularly revealing:

> The objective of an inquiry-based lesson is to give students the opportunity to familiarize themselves with magnets, and especially with their magnetic poles. Initially, the teacher problematizes his students, and then students experiment and test their hypotheses. The teacher does not provide ready-made responses, but evaluates students through appropriate questions. (Teacher #29, before the course, cluster of inquiry: *basic*)

> The teacher introduces students to a problem that relates to why some objects sink and some others float in water. She prompts students to pose their initial ideas (these might relate to the identification of variables that might affect the sinking/floating of objects), and helps students to formulate hypotheses that would later test through experiments. Before formulating hypotheses, the students formulate investigative questions in the form "Does variable A affect variable B?", and for each question they formulate a hypothesis. Next, the students are asked to choose a question and design a controlled experiment (only one variable is altered while the rest are maintained constant) for answering it. During their experiment, they collect data, organize them in a table, and when they have collected enough data, they proceed in interpreting their data in relation to their initial hypothesis and investigative question. The students follow the same procedure for answering all investigative questions, and the support from the teacher faints out, as she observes that the students are able to transfer the experimental design strategy for investigating the effect of new variables in the sinking/floating of objects. (Teacher #29, at the end of the course, cluster of inquiry: *advanced*)

Teachers' knowledge of *children's understandings and misunderstandings associated with inquiry* has improved by the end of the course. During Phases 1 and 2, the majority of teachers were classified in the naïve inquiry level (see Table 1), and it was at the end of Phase 3 and 4 weeks after the course that they made a significant progress to the advanced inquiry level (69% and 91% in advanced inquiry, respectively, see Table 1). For instance, in a task that teachers were prompted to refer to the inquiry skills a student should master in order to engage in inquiry, a teacher in the beginning of the course stated the following:

> It is essential that students should be able to collaborate with each other and follow specific instructions. Also, it is important that students are not used of receiving ready-made knowledge, but be able to formulate conclusions themselves. (Teacher # 11, cluster of inquiry: *naïve*)

Based on the abovementioned response, it is obvious that this particular teacher failed to reflect and name some of the inquiry skills that a child should have already developed in order to meaningfully engage in inquiry activities. After teachers' participation in the three consecutive phases of the PD program and specifically after working with an elementary school student for the purposes of the science fair project, the majority of teachers appeared to be able to make statements on the skills that are fostered within an inquiry-oriented instruction. The following quote from a participant's response documents this assertion:

> A student should have mastered several inquiry skills in order to enrol in inquiry activities. These skills are as follows: (i) identification of variables skill; (ii) formulation of investigative questions skill; (iii) control of variables skill; (iv) data interpretation skill; (v) hypothesis generation skill; (vi) hypothesis testing skill. (Teacher # 3, cluster of inquiry: *advanced*)

As far as teachers' *understanding of the instructional strategies and tools for supporting inquiry* is concerned, a similar pattern of improvement was revealed. Specifically, to evaluate this aspect of PCK for inquiry, we administered to the teachers a set of scenarios that illustrated how different teachers approached the teaching of the same topic with their students. The teachers were prompted to choose which of the scenarios involved instructional strategies and tools for supporting students' engagement in inquiry. One of the scenarios was as follows:

> Mr. Lowe is a 3rd grade teacher. One of his eventual objectives is for students to learn (at a simple level) about the relationship between form and function. He begins a specific lesson on fish by showing an overhead transparency of a fish, naming several parts, and labelling them as shown. (Adapted from Schuster et al. 2007)

Prior to the course, the majority of teachers' responses were clustered as naïve, since they considered this lesson as inquiry-related and provided arguments like:

> This is a good lesson, because the teacher aims to introduce the terms in a systematic way that the children will need while studying the fish.

Or,

> I consider this a good lesson, because learning about fish function should start by introducing the names of the fish parts to students, and then proceed on studying how these affect the function of the fish.

At the end of the course, teachers' evaluations of the same lesson scenario appeared to have changed since they considered it as not an inquiry-oriented one. To document their evaluations, they provided responses like the one below:

> This lesson is not appropriate, because it follows a content delivery approach (e.g. the teacher provides the names of parts of the fish to the children) and there is no evidence to show that the teacher aims to prompt students to develop questions and hypotheses of how and why each part of the fish affects its function.

This finding can also be attributed to the rich teaching and learning experience they received during their efforts to engage their students with inquiry-based activities and scaffold the development of their inquiry skills and understandings about critical aspects of inquiry (Phase 3 of the PD program).

Discussion

The purpose of this study was to investigate the effect of a PD program on teachers' development of inquiry competence. The findings demonstrate significant shifts of teachers from naïve to advanced inquiry in all three aspects of their inquiry competence (inquiry skills, definitions of inquiry, and PCK for teaching science as inquiry).

These promising findings can be attributed to two important aspects of the PD program that was designed and followed for the purposes of the present study. The first relates to the *features of the course*, such as, the format and structure, the curriculum materials, and the teaching approach. The second one is associated with the three distinct *participatory roles* that teachers were assigned to during their engagement in the three consecutive phases of the PD program. We briefly elaborate on each of them below.

Features of the Course

All *nine critical features of effective inquiry* derived from Capps et al. (2012) were addressed in the design and were successfully implemented during the course. As far as the *structural features* of the course are concerned, the *total time* of the course (12 weeks) compared with the duration of the reviewed studies by Capps et al. (from 1 to 6 weeks) provides a significant time difference that allowed both instructors and participants to work out several important learning and teaching activities without being constrained by the time factor. Consequently, PD programs should provide teachers with adequate time frames to deconstruct their understandings about learning and teaching through inquiry (Capps et al. 2012) and eventually to modify their teaching practices (Supovitz and Turner 2000).

Also, the *extended support* provided to teachers at various instances during each phase of the course might also account for the significant inquiry gains that were evidenced in their reports and presented in the Findings section. For instance, during Phase 3 (teachers as reflective practitioners), the teachers received feedback on their science fair project proposals by the instructors of the course. They also met with the instructors once a week on a volunteer basis to pose questions, discuss problems encountered during the meetings with their students, and get support on their future steps. The support received was also extended and enhanced via online communication; a social network page was created to offer teachers the opportunity to exchange ideas with their peers, to share learning experiences and discuss the lessons learned from the meetings with their students, and also to receive feedback on their lesson plans and curriculum materials from the science teachers of the local school that their students came from. Hence, it appears that extended support is vital during teachers' professional development. This is in agreement with the literature of the domain, which postulates that the provision of support influence teachers willingness to change their teaching practices (Simon et al. 2011).

The third structural feature of the course, namely *authentic experiences*, is also considered as an important factor for teachers' inquiry learning achievements. For instance, during Phase 1 (teachers as learners), the teachers were engaged with a curriculum developed for the purposes of this course titled "Boiling and Peeling Eggs," and they were prompted to answer "How to make perfect hard boiled eggs that are easy to peel?" Specifically, the teachers (working in groups of four) defined the problem that merited solution; identified variables that might affect the boiling and peeling of eggs; formulated investigative questions and hypotheses; designed and performed valid experiments to answer their questions and test their hypotheses; collected, analyzed, and interpreted data derived from their experiments; drew conclusions from the data; and presented their findings in posters to communicate with the rest of their peers. They neither received lecturing on what inquiry is and how it is performed nor were given ready-made experiments to follow in answering their questions. Instead, they worked in the science lab for an extended amount of time aiming to produce reliable knowledge on the topic of boiling and peeling eggs that could not be found in books, the Internet, etc. Accordingly, teachers who receive authentic inquiry experiences – similar to those they will implement at a later stage in their classroom – are expected to be able to better translate their learning experiences to their students, better communicate and relate concepts to their students, and have a higher impact on enhancing students' interest and achievement in science (Dubner et al. 2001).

As far as the *core features* of the course are concerned, we took into account the five features introduced by Capps et al. 2012. Firstly, with regard to the feature of *coherence*, a serious attempt was made to follow the inquiry paradigm while designing the course, given that inquiry-based learning is manifested in the national curriculum of Cyprus and the science textbooks' units are considered to have been developed on the tenets of the inquiry-based approach. Thus, the compatibility and coherence of the aims and content of the course with the national curriculum (Ministry of Education and Culture 2016) was expected to facilitate and support teachers' teaching practice when entering the school for the purposes of their school practicum the following academic year. This conjecture is in line with what Grant et al. (as cited in Garet et al. 2001: 927) claimed; namely, if the sources used for teachers' training "…provide a coherent set of goals, they can facilitate teachers' efforts to improve teaching practice, but if they conflict they may create tensions that impede teacher efforts to develop their teaching in a consistent direction."

Secondly, the *developed lessons* feature might account for teachers' significant development of their PCK for teaching science as inquiry (Akerson et al. 2009; Basista and Mathews 2002). Specifically, during Phase 3 (teachers as reflective practitioners), the teachers were asked to develop lesson plans and curriculum materials that they would use in engaging a student in inquiry-based activities for the purposes of the science fair project. In developing their lesson plans, the teachers formulated learning objectives and designed activities that were aligned with the principles of inquiry-based learning (e.g., students would learn how to formulate investigative questions, test hypotheses, develop and apply the control of variables skill, design and perform controlled experiments, make inferences from the data collected, use evidence to develop explanations, etc.).

Thirdly, the *modeled inquiry* feature enabled teachers to experience firsthand how inquiry-based instruction looks like in practice and thus to appear more ready and confident in their own field of practice for scaffolding their students' learning pathways while involved in inquiry-based activities (Putnam and Borko 1997; Radford 1998). Specifically, the participating teachers (working in groups of four) were assigned to the role of learners during Phase 1 of the course and followed the specially designed curriculum to complete activities and evaluation tasks in an attempt to learn firsthand how inquiry-based learning looks like in the curriculum. The teachers discussed the progress of their work with the course instructors during "checkout points" placed in specific stages of the curriculum. The instructors aimed to engage teachers in semi-Socratic dialogues during the checkout points, instead of merely answering questions or providing the correct answers to the activities of the curriculum.

Fourthly, the *reflect* feature enabled teachers to become thinkers of their evolved conceptualizations of various aspects related to inquiry along the course and thus to develop sophisticated understandings of inquiry and inquiry-based learning (Clift et al. 1990). This was accomplished in Phase 1 during which the teachers were asked to keep reflective diaries to record their evolved understandings of inquiry, the questions and problems that emerged during working with the curriculum to answer the investigative questions they formulated, and their impressions from the course. In addition, when teachers were involved in the teachers as thinkers phase (Phase 2), they were asked to reflect on the curriculum in which they were engaged in the previous stage as learners from the lens of its pedagogical rationale and discuss how inquiry skills and knowledge were fostered within specific learning activities. Through reflection – which is considered of pivotal importance for the success of teachers' professional development courses – teachers are empowered to apply changes in both the content and the pedagogy of their practices (Fenstermacher 1994).

The fifth core feature of the course, namely, *transference* (which might be associated with the development of teachers' PCK for teaching science as inquiry), was integrated in the course when teachers adapted the format and structure of the curriculum they were engaged with (Phase 1), in order to design their own curriculum to be used during the engagement of an elementary school student in inquiry-based activities for the purposes of the science fair. During the design of their curriculum materials, they received feedback from the instructors on certain aspects of their work, which was proven beneficiary in transferring the PD materials and experiences in their own field of practice.

Lastly, the course not only focused in engaging teachers in inquiry-based activities but also on helping them develop specific content knowledge, including understanding of certain aspects of the nature of science, the nature of scientific inquiry, and the science concepts that related to the context of the curriculum (e.g., boiling, heat and temperature, egg protein denaturation, etc.). Developing teachers' content knowledge was an important aspect of the study's PD course. This is in accordance with Capps et al. (2012) work, which claims that if teachers' development of adequate content knowledge is neglected within their training, "they will likely be uncomfortable with the material they teach and have difficulties when they attempt to teach the material" (Capps et al. 2012: 302). Additionally, the course gave emphasis on promoting teachers' development of inquiry skills, such as the control of variables, the design of controlled experiments, the data interpretation, the identification of experimental flaws in given experimental designs, etc. Based on the reported findings that relate to teachers' development of inquiry skills and informed understandings of inquiry, the core feature that relates to *content knowledge* is another source to take into account when interpreting the findings of the present study.

Participatory Roles of Teachers

Teachers' learning gains in terms of inquiry skills, definitions of inquiry, and PCK for teaching science as inquiry development can also be attributed to the three participatory roles that they were assigned to during each of the three consecutive phases of the PD program. Firstly, during Phase 1, the teachers as *active learners* experienced themselves how inquiry-based instruction looked like. Their engagement with the specially designed curriculum "Boiling and Peeling Eggs" enabled them to walk through the same learning journeys that their students were expected to follow, and based on the analysis of their responses in the pre- and post-assessment tasks that sought to evaluate the level of their inquiry skills, it appeared that the learning experiences received during Phase 1 enabled the significant development of inquiry skills (see Table 1 for more details). This finding is in line with Loucks-Horsley et al. (1998) claim that engaging teachers as learners in the context of PD programs impact on the construction of meaningful knowledge about inquiry and skills for inquiry teaching.

Secondly, the designed activities that teachers engaged with as *thinkers* during Phase 2 (e.g., identification of the phases and subphases of the inquiry learning framework that the curriculum they worked with during Phase 1 was designed on, reflection on the learning objectives that were fostered through certain activities of the curriculum of Phase 1, etc.) seemed to have helped them to improve their understandings of what inquiry is (see Definition of inquiry, Phase 2, post findings in Table 1) and their knowledge of appropriate curriculum for inquiry (see Knowledge of appropriate curriculum, Phase 2, post findings in Table 1).

Lastly, the findings at the end of Phase 3, during which teachers were positioned as *reflective practitioners* and were asked to design and implement curriculum materials for the purposes of the science fair project and to collect evidence to evaluate and reflect on the effectiveness of their teaching, demonstrate significant development in all three aspects of their inquiry competence. Hence, as Freese (1999) put it, these learning gains that resulted because of teachers' role of reflective practitioners are expected to affect positively their inquiry practices both during their preservice and in-service teacher placement.

Lessons Learned

In this study we aimed at developing a PD program that could positively impact teachers' development of inquiry competence. It appears that our approach, particularly the *features of the course* and the three distinct *participatory roles* that teachers were assigned to during their engagement in the three consecutive phases of the PD program, was particularly effective. The latter has a number of implications on how PD programs on inquiry should be enacted. For example, it is apparent that teachers would benefit from each of the three aforementioned roles in a way that would enable them to capture the inquiry competence in its entirety, because each role has something unique to offer that the other two roles do not entail. Of course, further research with larger samples is needed for reaching more concrete and generalizable conclusions.

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