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Evaluating Inquiry Practices: Can a Professional Development Program Reform Science Teachers' Practices?

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ABSTRACT

In the last 30 years, there has been an ongoing discussion about the effectiveness of Professional Development (PD) programs, which aims to promote reform-based Science Education (SE). Among the many, different trends of reform-based science teaching, inquiry-based approaches hold a dominant role. This study shows how teachers' practices were affected by a PD program that aimed to familiarize them with reform-based teaching through gradual instructional design, with the main focus on inquiry. The PD program had a duration of 12 months and involved four science teachers (two primary and two secondary) who were trained in both in and out of school teaching settings. The changes in teachers' practices were recorded through an observation protocol containing predefined categories in eight domains, one of which––that of inquiry––is discussed in this paper. A semi-quantitative method was used for data analysis. Results indicate that all the teachers had an overall improvement in the domains of guided inquiry practices and student-centered teaching approaches. However, there did not appear to be any substantial progress in open inquiry practices. Restrictions of the present study are presented, and suggestions for improving future PD programs promoting sustainable inquiry implementation are also discussed.

KEYWORDS

Science Education (SE); Professional Development (pd); inquiry-based teaching; Teaching Learning Sequences (TLS); non-formal science education

Introduction

In the last 30 years, a large part of research in science teaching and learning has focused on Professional Development (PD), with an aim to empower in-service teachers, improve their teaching strategies, and update their skills and knowledge in accordance with current trends in Science Teaching (ST). These studies identify the features of programs, which besides being similar, are considered to be essential for teacher development (Avalos, 2011; Capps et al., 2012; Darling-Hammond & Richardson, 2009; Shaharabani & Tal, 2017). Among the many different trends of reform-based science teaching, inquiry-based approaches play a dominant role (Capps et al., 2012; Janssen et al., 2014; Schwarz, 2009).

Substantial work has been done in the attempt to map existing research on Professional Development programs that promote inquiry and reform-based inquiry teaching (Aldahmash et al., 2019; Capps et al., 2012). An extended review of the empirical research has been conducted by Capps et al. (2012) to clarify the terms and conditions that influence

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the effectiveness of PD programs, including the methods, the content, as well as the context that these programs take place in. In the aforementioned study, reviews of inquiry PD programs have brought to light a number of common characteristics, drawing attention to teaching design (e.g., lesson plans) and implementation (e.g., observation of teachers' practices) to record possible development. Other researchers have suggested that making connections between non-formal and formal science learning environments is an innovative way of transforming science teacher preparation and development in order to meet the needs of science education reform (Čáp, 2007; Mc Ginnis et al., 2012). Ainsworth and Eaton (2010) elaborate on this view by claiming that inclusion of different learning frameworks (e.g., formal, informal, and non-formal) helps to develop multiple knowledge and skills from each context by integrating them into students' knowledge.

In the present study we describe a science teachers' PD program, which aims to familiarize participants with current trends in science teaching. More specifically, the program focused on inquiry instructional design, and involved science education in non-formal settings. The leading research question was as follows: Can an in-service reform-based, long-term Professional Development program change teachers' inquiry practices in blended educational settings?

Theoretical framework

Professional development aiming to promote reform-based teaching

In this section, we examine the literature relating to PD programs aiming to promote reform-based teaching. We also present research findings of the factors that make PD programs effective, focusing attention on the characteristics that promote inquiry approaches and the challenges they pose.

It goes without saying that science teachers are expected to teach in innovative ways that are different from their own experience as students (Shaharabani & Tal, 2017). Teachers are also expected to acquire and upgrade teaching competencies, incorporate contemporary teaching strategies and be informed about advancements in subject knowledge (Donaldson, 2011). In this sense, many PD programs are designed to help teachers develop their knowledge, skills, beliefs, and practices in order to improve students' learning (Luft & Hewson, 2014). Many studies focus on the conditions that make PD programs effective (Avalos, 2011; Darling-Hammond et al., 2009), the specific science content they promote (Aldahmash et al., 2019), the way teachers' views or practices may be affected (Mansour, 2014; Rushton et al., 2011), or may interact with each other in more complex ways (Buehl & Beck, 2015). At the same time, there seems to be little knowledge about the long-term effects of PD programs, particularly those involved with actual practice (Shaharabani & Tal, 2017). Aldahmash et al. (2019) state that such programs can be more effective when they are extensive (Darling-Hammond & Richardson, 2009; Yang et al., 2018), based on active, reflective forms of learning, and are job embedded (Harris, 2016).

Research findings on PD programs reveal that when teachers are engaged in experiences that demonstrate a given methodology, they have a better understanding of the instructional processes they are called on to implement (Lotter et al., 2016). Other researchers have shown the provision of in-class scaffolds for inquiry implementation, which are teacher needs-specific, to be vitally important for PD programs (Lotter et al., 2013; Schneider et al., 2005). Aldahmash et al. (2019) state that effective PD programs offer opportunities for both formal and informal in-service development, as they engage teachers in professional learning for a substantial period of time, offering them opportunities for collaboration, which are built into teachers' work hours. This is in support of the findings by Lotter et al. (2016), which claim that effective PD programs should contain activities embedded in teachers' contexts that run for a specific period of time. It has also been suggested that teacher development and learning is more successful when it includes the necessary Pedagogical Content Knowledge (PCK) which science teachers need to master in order to use inquiry as an alternative approach in teaching (Aldahmash et al., 2019). Most researchers agree that the lack of content, or of pedagogical and procedural knowledge, can inhibit change in teachers' practices. Bybee and Loucks-Horsley have aptly stated that: "Teachers need to know science as deeply, even more deeply, than their students" (Bybee & Loucks-Horsley, 2001, p. 4). Another study (Capps et al., 2012), found that there are a number of reasons why most teachers do not routinely use inquiry-based instruction in their teaching, and that the problem is apparent in elementary and middle school where teachers lack familiarity with the fundamentals of scientific inquiry and inquiry-based instruction.

Unfortunately, few classroom teachers have had the opportunity to participate in scientific inquiry, while it has been shown that even some of the most highly qualified teachers have limited implementation knowledge of inquiry (Akuma & Callaghan, 2019; Chichekian & Shore, 2016; Tsaliki et al., 2016). In their study, Bevins et al. (2019) found that initial teacher education and PD programs had weaknesses, and in many cases, failed to promote inquiry effectively as an approach to science teaching. Thus, a major challenge in the field of PD is to assist teachers in understanding how to enact inquiry-based instruction in their classrooms (Capps et al., 2012; Lotter et al., 2016; Shaharabani & Tal, 2017). This difficulty is also reported in the literature review by Capps et al. (2012), who found very few empirical studies specifically related to science-inquiry professional-development programs, which were in alignment with features for effective PD. This lack of effective PD characteristics may likely be the missing link that helps teachers implement inquiry-based instruction in their own classrooms. In addition, they stress the need to link enhanced teacher knowledge to changes in actual classroom practice, which can be accomplished by offering adequate time in real classroom conditions, as well as supporting teachers to adapt their lessons so that they are congruent with inquiry-based instruction. This approach seems to be in accordance with the PD notion "science teacher as learner," which proposes that teachers are seen as active participants in their own learning (Lotter et al., 2016; Loughran, 2014), and thus, play an important role as far as teaching design is concerned. Lotter et al. (2013) acknowledge there is difficulty in PD programs promoting inquiry implementation in school practice, and suggest that these programs should also address teachers' beliefs, involve participants in collaborative communities, and provide teachers with long-term support to encourage them in the use of inquiry practices. As an important prerequisite to the implementation of inquiry practice, among others, they stress that teachers need to have a strong conceptual understanding of inquiry-based teaching. Additionally, reflection on practice and beliefs has shown some promise in helping teachers implement inquiry (Akuma & Callaghan, 2019; Capps & Crawford, 2013; Capps et al., 2012; Lotter et al., 2013). Finally, other recent studies have emphasized the significance of providing a friendly context for collaboration with peers in order to support inquiry teaching (De Luca et al., 2015; Papaevripidou et al., 2017) and increase PD effectiveness.

Summarizing literature, we can state that general characteristics related to successful PD programs involve participants' extensive engagement in their working context, interaction and peer collaboration, inclusion of formal and non-formal settings, as well as given methodologies to guide them during their teaching attempts. Additionally, more empirical studies are needed on what constitutes efficacious inquiry programs in order to connect given theory to effective inquiry implementation. The most commonly mentioned parameters related to inquiry PD programs are: a deep conceptual understanding of inquiry; scaffolding methodologies that help teachers, on the one hand, to engage as active learners, and, on the other to participate in the creation of teaching design; adequate practice time in school settings, and a focus on teachers' needs with the aim of providing them with long-term support and encouragement. These conditions facilitate the teacher's role, but also engage them in active learning, which enables them to become reflective practitioners in the PD process.

Inquiry as a dominant approach in reform-based teaching

In this section, we present the concept of inquiry as it is described in reports of the American National Research Council (NRC) (National Research Council, 1996, 2000, 2012), as well as in curricula and other research studies. Additionally, the benefits that make it a compelling and effective proposal for teaching and learning are also examined. Furthermore, we elaborate on the classification of inquiry approaches met in research, based on the degree of given guidance.

It has been argued that inquiry-type teaching is considered important in the teaching of science as it aims to familiarize students with scientific procedures based on active learning and the construction of knowledge (Vorholzer & Von Aufschnaiter, 2019). More specifically, the term "scientific inquiry" is applied to describe a multiple of ways that scientists use to investigate the rules that characterize the natural world (Liang & Richardson, 2009). Inquiry is described by the NRC (National Research Council, 1996, 2000, 2012) as a versatile activity involving the growth of research skills, selection, integration, and evaluation of information, as well as the searching in active ways for answers to questions about specific scientific concepts. In addition, it has been stated that engaging students in advanced inquiry practices contributes to effective learning, motivation, critical thinking, communication, and an increased interest in science content (Schwartz, 2017). Other researchers focus on the fact that inquiry provides a reasonable background that helps students understand how scientific innovations are created, and introduces them to both scientific content and scientific methods (Smolleck et al., 2006). Inquiry approaches are regarded as supportive for education of sustainable development as they offer to teachers and students alike, the appropriate tools for ongoing learning and the understanding of science (Aldahmash et al., 2019).

Most scholars accept the fact that inquiry teaching has multiple phases with many different actions. In a literature review by Alake-Tuenter et al. (2012), six basic teaching components characterizing inquiry were detected, which are also addressed in other studies (Avraamidou & Zembal-Saul, 2010; Lin et al., 2009). These components, which refer to students' actions, are the following: (a) asking scientifically oriented questions, (b) conducting experiments and tests to collect data, (c) prioritizing data related to the questions asked, (d) formulating explanations to interpret their data, (e) linking interpretations to already existing scientific knowledge, and (g) communicating, presenting, and documenting interpretations.

Two other important parameters of inquiry teaching that most commonly attract the interest of researchers are the type and degree of guidance provided during inquiry implementation. The types of inquiry approaches span over a wide spectrum, ranging from extremely teacher-centered and structured inquiries at one end, to learner-centered inquiry designs at the other (Akuma & Callaghan, 2019; Bevins et al., 2019; Blanchard et al., 2010; Furtak et al., 2012; Varma et al., 2009). For the classification of an inquiry activity as completely or partially guided, structured, or open, it has been suggested that the participation of both teachers and students needs to be estimated (Varma et al., 2009). Moreover, Akuma and Callaghan (2019) state that structured and directed inquiry is teacher-driven, whereas open inquiry is learner-driven. In an earlier study by Blanchard et al. (2010), inquiry approaches were put into four main categories: a) confirmatory, b) structured, c) guided, and d) open (see Table 1). In general, study findings are in agreement that when inquiry is implemented as a foundational method for the delivery of learning, it is needed to have consistent practice and a variation in the complexity of levels presented, in order for a deeper understanding of the course content to be developed. At the same time, it has been found that students' abilities and understanding of the method matures as they practice (Banchi & Bell, 2008).

Much of the existing literature tends to focus on structured or guided inquiry with limited reports on open inquiry. We would assume that this is because both structured and guided approaches are relatively process-driven, or what Bevins et al. (2019) refer to as "procedural." This affords teachers a large degree of control and, therefore, is easier to manage in the classroom than open inquiry, which requires the teacher to relinquish control to the students of significant areas, engaging them in continuous decision-making. Critics of inquiry-based teaching have argued, however, that its minimally guided approach does not provide sufficient structure to help students learn the important concepts and procedures of science (Furtak et al., 2012). The views of Hmelo-Silver et al. (2007) are in agreement with this argument, as they point to the fact that open inquiry activities increase the cognitive load required in order for them to be performed successfully, which can inhibit learning. Another study relates the degree of provided guidance to the type of teaching goals initially set by the teacher (Vorholzer & Von Aufschnaiter, 2019).

Many studies identify the challenges teachers are confronted with when attempting—or have been assigned—to implement open inquiry (Almuntasheri et al., 2016; Zion et al., 2007). It has been indicated that when a teacher has little or no experience in conducting an

Table 1. Levels of inquiry and their characteristics.

Levels of Inquiry	Poses questions	Choice of data collection method	Data interpretation
Level 0- Verification inquiry	Teacher	Teacher	Teacher
Level 1- Structured inquiry	Teacher	Teacher	Students
Level 2- Guided inquiry	Teacher	Students	Students
Level 3- Open inquiry	Students	Students	Students

Source: Blanchard et al. (2010, p. 581).

open inquiry-lesson, a guided inquiry-learning approach is the “ideal” form (National Research Council, 1996). In order to cope with feelings of insecurity about science education, teachers rely on methods and materials whereby pupils primarily follow instructions (Zion et al., 2007). In their study, Van Uum et al. (2016) found that open inquiry-based science teaching poses challenges for primary school teachers, as they often lack experience in supporting their pupils during the different phases of the procedure, such as formulating a research question or designing and conducting an investigation. Moreover, the open inquiry approach offers considerable autonomy to students, which consequently makes the teacher’s role more demanding.

As in numerous other countries, it is common ground also in Greece that science teaching in everyday practice focuses mainly on declarative knowledge (concepts, phenomena, laws, and principles, etc.) rather than on the processes that produce knowledge and validate it (Kariotoglou et al., 2012). Similar conclusions can be found in other European countries where studies report that knowledge in classrooms is mainly produced in a deductive way, while inquiry, in the best case, is restricted to recipe-style investigations that fit the requirements set by the national education policy (Bevins et al., 2019). This fact is attributed, among other contextual reasons, to lack of relevant teacher training, resulting also in low levels of epistemological understanding of science in the educational community (Duschl & Grandy, 2008; National Research Council, 2012). Teachers’ difficulties in implementing inquiry approaches have been documented by many researchers (Capps et al., 2012; Tsaliki et al., 2016). A strong conceptual understanding of science content is considered a perquisite for inquiry-based teaching (Lotter et al., 2013), while teachers’ contextual dissatisfaction with reference to time constraints, curriculum requirements, environment, and self-efficacy reasons have arisen as factors affecting inquiry teaching (Bevins et al., 2019). For this reason, researchers in the field of professional development and learning find it important to develop effective ways of disseminating inquiry processes not only to students (Flick, 2006; Janssen et al., 2014; Zoupidis et al., 2016), but also to teachers (Gelman et al., 2010; Schwarz, 2009; Zoupidis et al., 2017) for all levels of schooling, from primary to secondary education.

In sum, in spite of its benefits, the implementation of inquiry has been shown to be limited. Among the contextual reasons for dissatisfaction, such as time and curriculum constraints, researchers have also noted a lack of inquiry teaching experience, a lack of appropriate teachers’ training and conceptual understanding of the method, which leads to insecurity in science education. Finally, it should be stated that there appears to be a genuine need to spread inquiry implementation extensively through effective PD programs.

Reform-based teaching and the role of non-formal Science Education

As discussed in the literature review, a large number of PD programs pay particular attention to promoting inquiry teaching approaches. Furthermore, emphasis is also placed on the non-formal aspect of education as mixed or blended education (a mixture of formal and non-formal combined together) (Mc Ginnis et al., 2012; National Research Council, 2012).

Informal learning has been defined by the OECD (Werquin, 2009), as out-of-school learning that is unstructured and does not follow a specific curriculum, such as a visit to a museum or science exhibit. In contrast, non-formal learning is also out-of-school learning but has a specific structure and is connected to some kind of a syllabus or curriculum (Garner et al., 2014). Despite the official definition of the terms "informal" and "non-formal" science education (ISE and NFSE, respectively) and their wide use, they are often not coherently applied. Quite frequently the terms are used interchangeably to describe any educational event that takes place outside the school, or even outside regular classes. In this paper, we use the term non-formal education as it more precisely defines out-of-school activities that adhere to the curriculum. The important role of learning science in non-formal environments, as well as evidence that such an experience can promote and strengthen learning are evident in a number of studies and reports (Matthews et al., 2017; National Research Council, 2000, 2012). The unique characteristics of non-formal science learning may have a beneficial contribution to the formal learning of science teachers, as they are encouraged to adopt new practices (Mc Ginnis et al., 2012; Matthews et al., 2017).

Other recent studies (Tang & Zhang, 2020) based on PISA (Organisation for Economic Co-operation and Development, 2016) reports, show that the informal and non-formal science education experience has been extensively identified as an important complement to formal school science education, increasing the interest in learning science, and improving scientific literacy and performance. Additionally, reform in science education has set the goal of integrating non-formal science environments for elementary school teachers (Avraamidou, 2014). It has been suggested that ISE and NFSE increase the appropriateness, meaningfulness, and relevance of the formal science curriculum, particularly through inquiry learning, as well as contributing to the professional development of teachers (Avraamidou, 2014; Matthews et al., 2017). At the same time a strong body of research highlights the importance for teachers to be able to offer meaningful out-of-school visits through a combination of designing preparation, visit, and follow-up activities (Karnezou et al., 2021).

In this section, we clarified the terms NFSE and ISE, as well as discussing the way NFSE integration can invigorate science teaching and the PD programs that promote inquiry by empowering teachers with new skills that lead to better science teaching and learning.

Methodology

PD program characteristics

This paper studies the impact of long-term PD program titled "Program's name" (acronym). "Program's name" (acronym) aimed to gradually familiarize participants current trends of ST giving mainly focus to the inquiry approach, in order to enrich their teaching practices. The program was organized in three strands and our interest focuses on the 3rd mixed level (primary and secondary) NFSE strand. This specific strand aimed to familiarize participants with current trends in ST through gradual instructional design as part of preparing, conducting, and evaluating out-of-school visits to science and technology sites, to enrich school science effectively. It included both theoretical training on current trends of ST and classroom implementation on inquiry activities, designed to prepare students for an out-of-school visit and diffuse their inquiry findings to the local community. For training teachers in instructional design and inquiry implementation, Teaching Learning Sequences (TLS) were selected as the most appropriate method (Psillos & Kariotoglou, 2016).

The program's duration was 12 months. Since conventional PD methods have shown to be ineffective to a great extent (Borko, 2004), a more complex three-phase method was adopted. During phase 1, teachers' needs and expectations were recorded while participants were shortly observed during ST. Next, they were given a briefing about current trends in science teaching in a short-term, face-to-face, theoretical training consisting of seven sessions, lasting 21 hours in total (Tsaliki & Kariotoglou, 2018). The content of that training included inquiry teaching approaches, content transformation processes, issues related to procedural and epistemological knowledge, teamwork teaching, importance of taking into account students' alternative ideas, use of Information and Communication Technologies (ICT), use of models and modeling, the role of reflection, and the incorporation of non-formal settings in science teaching (Tsaliki et al., 2018). Moreover, in this phase, teachers were familiarized with the concept of TLS and their characteristics (Psillos & Kariotoglou, 2016). All issues were presented to teachers by lectures and subsequently discussed in plenary. During phase 2, participants were introduced to a readymade example of good inquiry practice. The example (TLS1) was a complete guided inquiry-based TLS, concerning properties of materials used in telecommunications and included activities conducted in school as preparation for an organized out of school visit. The example was given to be studied, possibly modified, and applied in their own classes as action research Finally, during phase 3, participants were encouraged to design their own inquiry teaching plans in interaction with each other. In this phase teachers' autonomy was significantly increased, as they chose the science topic for their teaching (i.e., electromagnetism), and co-developed, working in two pairs (primary and secondary) their own TLS from scratch, while the researchers gradually reduced the support provided up until then.

The program was designed to meet conditions and characteristics related to effective inquiry PD (Darling-Hammond et al., 2017), in addition to integration of NFSE, identified in the literature. More specifically, it took into account teachers' needs and expectations of a teacher training program (phase 1) and to engage them both during working hours and out of work time, for an extensive period of 12 months (Kariotoglou et al., 2017). The PD program was structured to promote peer collaboration among teachers and also among participants and researchers (Kariotoglou et al., 2016b). Both parts worked together as equal members of a team discussing and on the basic aspects related to reform-based teaching, the designing characteristics of the good practice example (TLS1) and those of TLS 2 and their implementation. Systematic support was provided to participants concerning science content, methodological, pedagogical and practical issues—relating to implementation, throughout the program. This support took place on a regular basis by scheduled (every 2 weeks), and spontaneous, nonscheduled meetings, asked when participants felt it as needed. Additionally, the program encouraged reflection on a personal and group basis, as an important aspect of effective PD. Teachers completed semistructured teaching diaries specially designed to promote reflection after every teaching session, while after the conclusion of every phase they had to provide written reports based on their teaching experience as whole. Additionally, they participated an organized group reflective discussion. The discussion was triggered by specific questions posed by trainers, concerning challenges teachers faced, possible alternative solutions, the way the program' s experience may affect their teaching design, etc.

The research

The basic aim of the research was to evaluate changes in science teachers' practices during and after their participation in the 3rd strand of "Program's name" (acronym). Overall, the research studied eight research domains (Kariotoglou et al., 2017): (1) inquiry, (2) students' alternative ideas, (3) types of verbal interaction, (4) formulation of the teaching content and its transformation during teaching, (5) use of ICT models and experimenting, (6) procedural knowledge, (7) epistemological knowledge, and (8) incorporation of non-formal settings into science teaching (NFSE). These domains, e.g., inquiry, content transformation, alternative students' ideas, NFSE, etc, were selected among others as the most commonly addressed issues of PD programs aiming to promote innovative ST (Capps et al., 2012; Khourey-Bowers & Fenk, 2009; Zhang et al., 2015). Moreover, some of them e.g., verbal interaction, use of models and modeling support inquiry implementation (Henze et al., 2007; Schwarz & Gwekwerere, 2007; Smart & Marshall, 2013) which was the main focus of the PD program. Also, relative literature provides indication that many of these domains, e.g., modeling and epistemological knowledge, modeling and conceptual change or content transformation and conceptual change, may evolve in parallel during PD programs (Minner et al., 2010; Osborne, 2014) which oriented our research interest for studying possible connections between them.

Since the aim of the study was to record teachers' Professional Development (PD), a combination of case study and action research approaches was adopted as the most suitable research methods. Action research is one of the most commonly used methods in education research, as it is effective in addressing certain issues, such as change of teaching methods and strategies (Cohen et al., 2007), while having a small number of participants is also common in case study research (Adelman et al., 1980). In this paper we present results regarding teachers' practices only on inquiry implementation.

The research was conducted in four schools in the regional unit of Florina in western Macedonia, Greece. Four teachers, two from primary education (one male and one female), and two from secondary education (two females), participated in the study. All participants had 11–24 years of teaching experience and were selected following an open call to the regional educational community. In Greece, primary school teachers tend to have extensive pedagogical knowledge due to their training, while secondary education teachers have deeper content knowledge of the subject matter. All the teachers had participated in the in-service seminars run by the School Advisors, none, however, had any in-depth training related to the eight research domains in this study. One of the secondary teachers had an MSc. The research question that guided us was as follows: Did science teachers' inquiry practices change in type and frequency after their participation in the PD program?

Teachers' initial profile was assessed regarding the design and implementation of science teaching, both in formal and in out-of-school settings during phase one. Teachers views about their practices were noted through face-to-face semi-structured interviews (views) and classroom observations (practices) (see Table 2). In the next phases (2 & 3) participants' views were recorded by semi-structured teaching diaries, on the eight domains mentioned earlier, written reports and reflective discussions that took place in the end of every phase. Practices were recorded by an observation protocol described thoroughly in the next section.

Research tools, data collection, and analysis

The methodology employed in this study is based on a semi-quantitative case study approach, where multiple interviews and observations were conducted over a twelve-month time period. This specific method was used in accordance with Lincoln and Guba (1985), who state that qualitative studies carried out over a considerable period ensure the trustworthiness of the research. Observation was considered most appropriate for documenting teachers' practices (Aldahmash et al., 2019; Coll & Coll). A teaching observation protocol was developed and used as a main research tool during all three PD program phases. In phase 1, each teacher was observed at least in one (1) teaching session (2 teaching hours x 45′ minutes), while in phases 2 and 3, teachers were observed for five teaching sessions, each one lasting two teaching hours (see Table 2). The observation protocol (OP) covered all eight research domains. Each domain was covered by several predefined questions referring to specific practices that could take place during teaching. The inquiry domain consisted of five subdomains including in total nine (9) questions (see Table 3). Although the literature suggests that guided inquiry is characterized by special features related to students' engagement in choosing the data collection method, we consider that the questions of the observation protocol describe a combination of structured and guided practices that suit the participants' teaching design during both TLS'. For this reason, we use both terms (structured and guided) in the description of subdomain B (see Table 3). For each question, the researchers noted the frequency of each teaching practice, on a 3-point semi-quantitative scale: 1 = Rarely, 2 = Sometimes, 3 = Usually. Additionally, the OP included an extra field, where observers could record indicative evidence (qualitative data), documenting examples of implementation of the specific practice (Table 3, last column). Each teaching session was observed and audio recorded by two independent researchers individually filling in the OP. When there was contradiction between the observers, a common agreement was reached by comparing field notes and audio recordings.

Table 2. Participants and phases of the PD program.

	Phases		
Participants/School Grade	Phase 1 (a) *Initial observation for at least 2 hours* (b) *Theoretical briefing*	Phase 2 (a) *Study and modification of good practice exam ple (TLS1)* (b) *Teaching & Observation for 10 hours/teacher of modified TLS1*	Phase 3 (a) *Designing TLS2 (minimum support by researchers)* (b) *Teaching & observation for 10 hours/teacher of TLS2*
Teacher 1 (Primary, 6th grade)	**Teaching topic**: Energy	**Teaching topics**: -Properties of materials used in telecommunications -Site visit to a telecom station	**Teaching topics**: -Energy Generation -Renewable and nonrenewable energy sources -Site visit to a power station plant
Teacher 2 (Primary, 5th grade)	**Teaching topic**: Properties of material (volume-weight-mass)		
Teacher 3 (Secondary, 9th grade)	**Teaching topic**: Electric Power and Charge (friction, induction and electrification by contact)		
Teacher 4 (Secondary, 9th grade)	**Teaching topic**: Coulomb's law		

Table 3. Example of the observation protocol: teacher 2.

Observation protocol		
2nd Teaching session -TLS 2 Date:		
Inquiry sub-domains	*Frequency of occurrence*	*Descriptive evidence*
A. Adoption of some kind of inquiry approach in general (mean = 2.67)		
1 Teacher poses questions/problems for scientific inquiry	3	*"Today we are going to see if the prediction you made last time about electromagnetism is true."*
2 Teacher encourages students to conduct research on a particular subject	2	*"You don't need to do something particular, just do your search as you understand it."*
3 Students conduct research using electronic or printed sources	3	Students are guided by the worksheet and search for the environmental policy, services and job descriptions of the working staff in the webpage for the local power producing agency
B. Adoption of structured or guided inquiry practices (mean = 2)		
4 Students perform pre-designed tests, experiments or research suggested by teacher or as included in textbook	1	No experiments suggested by the school textbook are executed -students. Students fill in tasks and questions from worksheet number 2, especially designed by Teacher 2
5 Teacher assigns experiments to students with worksheets	3	Students fill in tasks and questions from worksheet number 2, especially designed by Teacher 2 e.g: *Design a system (and explain what it includes) that creates a magnetic field without having a permanent magnet.*
C. Implementation of open inquiry practices (mean = 1)		
6 Teacher encourages students to plan their own research, make trials, do experiments, etc.	1	The activities mentioned in worksheet 2 do not encourage students to plan trials on their own. Teacher encourages students to follow course of actions indicated by worksheet 2. The worksheet contains questions that students need to answer critically thinking: e.g*: Do you agree to have other mines operating in your area and why?*
D. Communication of findings in plenary meetings (mean = 2)		
8 Inquiry findings and conclusions are announced in classroom by the teacher and/or students	2	Students present their findings and teacher interferes when he/she considers that it is needed, e.g., *Ok, so what exactly happened when you connected the battery cable to the compass?"*
E. Summary of teaching (mean = 2)		
9 All teaching/learning actions are summarized by a) teacher b) students	a) 3 b) 1	Teacher starts to describe the actions taken during the inquiry and in the end asks students:*"What is the important application that Faraday came up with?"*

*The final coding scheme (A-E) including the specific sub-domains (1–9) is also indicated.

All collected data were processed on Excel sheets, where the average frequency of each practice for each teaching session was calculated. Subsequently, the average occurrence of each practice, in each sub-domain, for each phase and for each teacher was also calculated. In addition, the mean frequency of occurrence resulting from phases 2 and 3, for each practice was also calculated. Following this, average frequency of practices in phases 2 and 3, was compared to those of the initial observation (phase 1) for each teacher, which was likewise the case for each teaching practice and for each inquiry subdomain. This comparison enabled us to identify possible development, stability, or regression in teachers' practices. Additionally, we compared frequency changes between primary and secondary teachers in an attempt to identify possible similarities or differences between the two educational levels.

During the data analysis, the need emerged, beyond numerical assessment, to characterize teachers' development in specific terms in order to reach in meaningful conclusions. More specifically, based to the scoring system of the observation protocol, the maximum difference between the scores was two points (max: 3, min:1, maximum difference = 2). In order to transform observation scores into meaningful outcomes, a classification scheme was developed. The key points of this classification scheme were determined by criteria suitable for this purpose (Cohen et al., 2007), based on the available data, and the differentiation they offered. Therefore, the following classification scheme was adopted, where frequency differences:

- between 0.20 and 0.40, were considered **low**, as they represent a change range between 10% and 20% of the total scoring range (0.2/2 = 0.1 or 10%).
- between 0.41 and 0.80, were considered **moderate**, as they represent a change range between 21% and 40% of the total scoring range.
- between 0.81 and 2 were considered **high**, as they represent a change range over 40% of the total scoring range.

Finally, frequency differences below 10% were considered **negligible** and were characterized as **neutral.**

Subdomain E (i.e., "who summarises the teaching") consisted of two different parts (see Table 3). The first (a, "the teacher summarizes") describes quite a traditional practice, while the second (b, "the students summarize") indicates a more reform-based approach. Since both of these practices could easily occur simultaneously to some extent during teaching, we addressed this issue as follows: We calculated the average frequency of the teacher's (FT) and the students' (FS) participation in summarizing teaching, with the highest frequency to indicate which of the two contributors was the most dominant. Given that students' frequency of participation (FS) would be the desirable innovative practice outscoring the more traditional one (that of teacher FT), the difference of these two frequencies was calculated, by subtracting teacher frequency from that of the students (FS—FT). Thus, negative results suggest that the teacher's role in the respective part of teaching was dominant, while positive scores indicate students' participation in summarizing was higher than that of the teacher.

Results

The results for sub-domain A "Adopting some type of inquiry approach in general" were very encouraging as both primary and secondary teachers presented a high level of improvement (Table 4). Three out of the four teachers (1, 3 & 4, Table 4) gained the lowest mean implementation frequency scores in phase 1, while their final mean implementation frequencies were very high, producing large average frequency differences, all above 50%.

Regarding sub-domain B "Adoption of structured or guided inquiry practices," significant progress was also noted (Table 5). More specifically, teacher 1 (primary) changed the implementation of guided inquiry practices to a high degree (84%), while teacher 4 (secondary) also fell into the high category, showing a 47% increase in implementation. Descriptive evidence from the OP showed that teacher 1 shifted from a traditional teaching approach of giving lecture-like lessons and following the course as set in the textbook, to a guided inquiry approach, while teacher 4, who initially implemented mainly discovery demonstration practices also applied enhanced teaching practices to a substantial extent in the following phases. Teachers 2 (primary) and 3 (secondary), although also altering their teaching practices (38% and 22%, respectively), did so to a moderate extent. It should be noted here that although teacher 2 scored the highest mean implementation frequency in phases 2 and 3 (2.75), her improvement was moderate, because she was already implementing inquiry activities in the initial phase of teaching. On the other hand, in phase 1, teacher 4 used mainly discovery demonstration practices, while during phases 2 and 3 her role was limited to simply supervising and helping students when needed, and this is why she presents the lowest level of change (22%).

In subdomain C "Implementation of open inquiry practice" (Table 6), all participants present very low (neutral) changes in their practices, meaning that stability was recorded. The related descriptive evidence shows that the small increases in frequencies (<10%) for all teachers, can be attributed to an activity that offered students the opportunity to make choices beyond the teacher's guidance (e.g., freely select objects to test electric conductivity). Since open activities were extremely limited in the overall teaching design organized by teachers, their implementation frequencies consequently were low.

Table 4. Sub-domain A -Teachers' development in adoption of some kind of inquiry approach.

Teacher/ School	Average Frequency				
	Phase 1	Phases 2&3	Difference (Phases 2&3—Phase 1)	Percentage of change	Magnitude of change
Teacher 1/P*	1.00	2.64	1.64	82%	High
Teacher 2/P*	1.33	2.49	1.16	82%	High
Teacher 3/S**	1.00	2.06	1.06	58%	High
Teacher 4/S**	1.00	2.64	1.64	53%	High

*P = Primary school; **S = Secondary school.

Table 5. Sub-domain B—Teachers' development in adoption of structured or guided inquiry.

Teacher/ School	Average Frequency				
	Phase 1	Phases2&3	Difference (Phases 2&3—Phase 1)	Percentage of change	Magnitude of change
Teacher 1/P*	1.00	2.69	1.69	84%	High
Teacher 2/P*	2.00	2.75	0.75	38%	Moderate
Teacher 3/S**	1.67	2.11	0.45	22%	Moderate
Teacher 4/S**	1.67	2.60	0.94	47%	High

*P = Primary school; **S = Secondary school.

Table 6. Sub-domain C—Teachers' development in adoption of open inquiry.

Teacher/ School	Average Frequency		Difference (Phases 2&3—Phase 1)	Percentage of change	Magnitude of change
	Phase 1	Phases2&3			
Teacher 1/P*	1.00	1.19	0.19	9%	Stable
Teacher 2/P*	1.00	1.17	0.17	8%	Stable
Teacher 3/S**	1.00	1.15	0.15	7%	Stable
Teacher 4/S**	1.00	1.15	0.15	7%	Stable

*P = Primary school; **S = Secondary school.

Table 7. Sub-domain D—Teachers' development in presentation of inquiry findings.

Teacher/ School	Average Frequency		Difference (Phases 2&3—Phase 1)	Percentage of change	Magnitude of change
	Phase 1	Phases2&3			
Teacher 1/P*	1.00	2.05	1.05	53%	High
Teacher 2/P*	2.00	2.88	0.88	44%	High
Teacher 3/S**	1.00	2.05	1.05	53%	High
Teacher 4/S**	1.00	2.25	1.25	63%	High

*P = Primary school; **S = Secondary school.

Sub–domain D refers to the "Presentation of the inquiry findings" and all the teachers presented a high level of improvement (>40%) (Table 7). As in subdomain B, although teacher 2, who was implementing a guided inquiry approach from the initial phase 1, before intervention, gains the highest implementation frequency at the end of the PD program (phases 2 & 3, 2.88), ends up presenting the lowest improvement percentage (44%), which, nevertheless, is still considered to be moderate and thus, substantial. Besides the frequencies, descriptive evidence from the OP showed that the presentation of the findings in the plenary classroom was an inquiry step applied by both primary and secondary school teachers. Teacher had the highest percentage of change (63%).

Finally, an interesting aspect of the TLS implementation is evident in the last sub-domain E, which refers to who summarizes the actions that took place during teaching (the teacher or the students). The overall development for each teacher can be seen in the third column of Table 8, were the frequency difference between the initial phase (1) and the mean of phases 2 & 3 is presented. During the initial observation, Teacher 1 seems to dominate

Table 8. Sub-domain E—Teachers' development in summarizing teaching.

Summary ofteaching by:	Average Frequency		Difference (FS & FT) (Phases 2&3—Phase 1)	Magnitude of change
	Phase 1	Phases 2&3		
Students (FS_1)	1.66	**2.05**		$FS1_{2,3}$-$FS1_1$ = 0.39 (low)
Teacher (FT_1)	**3.00**	1.91		$FT1_{2,3}$-$FT1_1$ = −1.10 (high)
Teacher 1(FS_1-FT_1)	**−1.34**	**0.14**	**<u>1.48</u>**	High
Students (FS_2)	1.66	2.03		$FS2_{2,3}$-$FS2_1$ = 0.36 (low)
Teacher (FT_2)	**3.00**	**2.13**		$FT2_{2,3}$-$FT2_1$ = −0.87 (high)
Teacher 2 (FS_2-FT_2)	**−1.34**	**−0.10**	**1.24**	High
Students (FS_3)	1.00	2.00		$FS3_{2,3}$-$FS3_1$ = 1 (high)
Teacher (FT_3)	**2.50**	**2.08**		$FT3_{2,3}$-$FT3_1$ = −0.42 (mod)
Teacher 3 (FT_3-FS_3)	**−1.50**	**−0.08**	**1.42**	High
Students (FS_4)	1.00	**2.15**		$FS4_{2,3}$-$FS4_1$ = 1.15 (high)
Teacher (FT_4)	**2.50**	1.83		$FT4_{2,3}$-$FT4_1$ = −0.67 (mod)
Teacher 4 (FT_4-FS_4)	**−1.50**	**0.32**	**<u>1.82</u>**	High

FT = Frequency of Teacher summary. FS = Frequency of Students summary *With **bold** outmatching scores, underlined scores where students' participation was higher than teachers in phases 2 &3.

classroom summary to the detriment of the students (FT_1**3.00** > SF_1 average 1.66), /whereas, during the program (phases 2 & 3) the students (FS) appear to have an equally important role (FS **2.05** > FT 1.91). Consequently, Teacher's 1 progress presents1.48 points, which is classified as high. The results for the sub-domain E show that there was a high level of development for all four teachers. In the case of Teachers 1 (primary) and 4 (secondary), the average frequency difference is underlined (Table 8), which indicates that the students' (FS) participation was dominant during their teaching phases 2 & 3. Teachers 2 (primary) and 3 (secondary) also present a high mean difference, which likewise represents development. Although the participation of Teachers 2 & 3decreased substantially (high and moderate, respectively), while at the same time students' involvement increased (at a low level for primary school students, and a high level for secondary school students), both teachers' participation seems to have still remained dominant. For instance, the descriptive evidence notes that Teacher 2 asked students to start summarizing actions by describing step by step each activity from the worksheet, but then for each activity, she announced the reason why students made that trial or executed an experiment, as well as restating the conclusion–the scientific law or the concept that was reached at the end.

Overall, the results indicate that participants made significant progress in regard to guided practices and the summary of actions during teaching; however, their open inquiry practices did not appear to develop to any notable level.

Discussion

Based on the above findings, all participants, irrespective of which level of school they worked in, i.e., primary or secondary, presented a substantial improvement in the general adoption of some type of inquiry approach (subdomain A). This impressive improvement might be attributed to a short theoretical training they underwent before their classroom implementation, which provided teachers with necessary knowledge about inquiry. This finding seems to be in accordance with other research that states that a strong conceptual understanding of inquiry-based teaching is a prerequisite to teachers' implementing inquiry practices (Lotter et al., 2013). In addition, teachers' inquiry theoretical knowledge needs to be established, at least to an adequate degree (Lotter et al., 2016), which can then be followed by change in teachers' practices when these opportunities arise in a real classroom setting (Aldahmash et al., 2019; Capps et al., 2012; Lotter et al., 2016; Loughran, 2014). At the same time, phase 2 worked as a familiarization procedure and offered valuable time for teachers to try the reform-based approach suggested to them in the program. The example of good practice given to teachers worked as a scaffold, enabling them to combine the offered theoretical knowledge with practice in a real classroom situation. Other literature findings suggest that offering scaffolding (Van Uum et al., 2017), and good practice examples (Kariotoglou et al., 2016a) or what Goodnough (2010, p. 919) refers to as "knowledge of practice," like the one used in this program, are valuable to participants, as it usually facilitates understanding of how to implement inquiry-based instruction in their own classes (Capps et al., 2012; Lotter et al., 2013, 2016; Shaharabani & Tal, 2017). Additionally, familiarization procedures like that in phase 2, and scaffolds, positively affect teachers' attitudes toward inquiry application (Lotter et al., 2013; Luft & Hewson, 2014) Lastly, it is possible that the duration of the program, which in our case lasted 12 months, greatly contributed to the positive results. It has been shown that more extensive PD programs have better results than shorter interventions (Capps et al., 2012; Darling-Hammond et al., 2009; Yang et al., 2018).

As mentioned earlier for sub-domain B, the implementation of structured-guided inquiry practices, resulted in a significant improvement of teachers' practices from both types of schools, primary and secondary. The progress recorded in the structured-guided practices could easily be attributed to the design of the good practice example (TLS 1), which contained mainly team-work guided activities, such as the ones practiced by the teachers in phase 3. Lotter et al. (2016), similarly concluded that engaging teachers in experiences which demonstrate a given methodology is an important factor impacting their practices. In the present study, teachers were able to adapt the design of the good practice example to their students' needs (e.g., teachers provided for extra teaching time to familiarize students with simple group work before applying jigsaw-type teamwork). Teachers' need to adapt their practices in order to be congruent with their students' profile and the requirements within a specific framework, has been stressed by Capps et al. (2012) as an important stage of their professional growth, leading to effective PD. The program's design, which included teachers as active contributors to their learning, provided them with the flexibility to make several adjustments or take important decisions (Loughran, 2014), which had a positive effect on their performance. The importance of teachers' feeling confident to make decisions about inquiry implementation has been well highlighted in the related literature (Lewis et al., 2016; Lotter et al., 2016; Silm et al., 2017). Teachers are more likely to change their behavior and practices toward teaching strategies of inquiry when they have had positive implementation experiences (Yang et al., 2018).

Regarding open inquiry practices (sub-domain D), none of the participants showed any substantial improvement. This was—more or less—expected due to the fact that the good practice example (TLS 1) included only a very limited number of relatively open activities. A number of other researchers have likewise found that positive results for open inquiry practices are less frequent than those for structured or guided inquiry practices (Almuntasheri et al., 2016; Capps et al., 2012; National Research Council, 1996). For example, Zion et al. (2007) found that the two-year framework of their study was unrealistic for the acquisition of inquiry skills for both students and teachers. From this respect, the four participants in our study, in spite of their deficit in not having prior experience in inquiry practices, achieved remarkable results, as they managed to adapt their teaching design to a high inquiry level in a shorter period of time (1 year).

The results regarding who summarizes during teaching (sub-domain E), were likewise very encouraging, as all teachers were able to limit their intervention for this part of the inquiry, leaving room for their students' involvement. Although guided inquiry practices are considered to provide teachers with a large degree of control (Blanchard et al., 2010), we found that students' engagement can be substantially enhanced depending on the specific goals set by the teacher (Vorholzer & Von Aufschnaiter, 2019).

Conclusions and limitations

Overall, the present study bases it originality to the fact that very few empirical studies relate specifically to science-inquiry teaching aligned with features of effective PD (Capps et al. (2012), while studying inquiry implementation as part of encouraging teachers to prepare and thus take full advantage of out-of-school science visits is even more rare (Karnezou et al., 2021). Besides other effectiveness-related components of the program, its' originality lies on the programs gradual-based design. The readymade example of good practice (TLS1) and sufficient time for studying it, enabled teachers to intergrade successfully structured/ guided inquiry activities into their teaching plans on a trial basis. Moreover, results showed that this gradual procedure provided teachers' authentic inquiry experiences (Capps et al., 2012), empowering them to proceed with more confidence to design inquiries with more autonomy such as TLS2. Another feature contributing to the originality of this research is the way that teachers' practices were recorded systematically during implementation, by direct observation in classroom for an extended period of time (1 year). The majority of similar research due to practical reasons, usually provides results by limited in class observation or indirect data, such as teaching plans which may differ from actual classroom practice.

Finally, an intriguing finding of the research, is that the plurality of interaction of mixed educational level participants (primary and secondary) is beneficial for inquiry PD, helping teachers to encounter arousing pedagogical and conceptual challenges of implementation besides already mentioned reflection, peer collaboration and support by trainers (Darling-Hammond et al., 2017). For these reasons, we, respectively, believe that although our results rest on a small number of teachers, provide a significant perspective in enriching and contributing further to the discussion on inquiry focused Professional Development. Further research, long after teachers' participation in PD programs, would be most valuable to provide information about whether and to what extent inquiry remains, and how it is implemented in science classrooms.

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