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A Long-Term Study on the Effect of a Professional Development Program on Science Teachers' Inquiry

Christina Tsaliki [1,*], Penelope Papadopoulou [1], Georgios Malandrakis [2] and Petros Kariotoglou [1]

[1] School of Education, University of Western Macedonia, 53100 Florina, Greece; ppapadopoulou@uowm.gr (P.P.); pkariotog@uowm.gr (P.K.)
[2] School of Education, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece; gmalandrakis@eled.auth.gr
* Correspondence: tsalikix@gmail.com

Abstract: In this study we explore the effect of a professional development (PD) program on four science teachers' views and practices nearly a year after its completion, regarding inquiry implementation in everyday school practice. The PD program aimed to familiarize participants with current trends in science education (SE), putting emphasis on the inquiry approach. The basic research question guiding this study is whether science teachers' inquiry practices and views changed, and to which extent, long after their participation in the PD program. Teachers' practices were recorded, both during and after the PD, through non-participatory observation and were analysed through a semi-quantitative method. Teachers' views were also recorded both during and after PD through structured questionnaires and reflective interviews, producing qualitative data that were analysed. Findings are encouraging concerning the preservation of guided inquiry practices obtained during the program, while more open inquiry practices proved to be limited. Teachers' views concerning inquiry remained positive, also maintaining their innovative character.

Keywords: science education; professional development; inquiry-based teaching; teaching practices

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1. Introduction

Current trends in science education (SE) suggest that in-service teachers need to teach in innovative ways that may differ from their own experience as students [1]. Additionally, it is expected that teachers, throughout their professional life, will acquire and upgrade their teaching skills, integrate modern teaching strategies, and seek information about the evolution of knowledge produced in the subject they teach [2]. In this sense, many professional development (PD) programs are designed to help teachers develop their knowledge, skills, beliefs, and practices to improve students' learning [3].

The term "professional development" is usually used to address a person's progress concerning their professional role. In education, the term refers to teachers' development as they gradually obtain teaching experience while at the same time reflect on their teaching approaches in a systematic way [4]. For Pringle et al. [5], the term "professional development" refers to a systematic attempt aiming to bring changes in teachers' practices, deepen content knowledge of the teaching subject and consequently improve teaching and learning. Lee et al. [6] also consider that the main purpose of professional development is to enrich and improve the learning opportunities that teachers offer to students, by altering teachers' views about teaching and learning and empowering them to try innovative teaching practices.

Thus, in the last two decades, a considerable part of the educational research has focused on professional development programs intending to empower science teachers and inform their teaching strategies, knowledge, and skills according to current trends of science teaching [7]. The necessity of change in education so that it can effectively respond to the emerging needs of the times seems to be a key issue that always has and

most probably will continue to be one of the main concerns of the scientific community. The large number of research papers and literature reviews [1,8,9] with variety in research orientation and content confirms the above argument. Moreover, there seems to be limited scientific knowledge about the long-term effect of professional development programs, especially those that study this effect on the teaching approaches that teachers finally apply in everyday teaching practice [1].

Additionally, research has highlighted the crucial role that teachers' professional development plays in educational reform efforts [10]. Teachers are no longer considered as one out of the many factors playing a role in the reform process. They are considered as both carriers and recipients of change, which explains the reason why their professional development has been attracting recent substantial research interest. For instance, Mansour et al. [11] suggest that teachers' empowerment may offer a creative challenge for the providers of that professional development, and encourage them to work with teachers as partners who can take the lead in their own professional development, and not just as trainees who digest what can be offered to them. When teachers' voices are often silent in the process of professional development, there is a danger that the PD providers might ignore, modify, abuse, misinterpret or even distort them [12]. All these are possible reasons why, in several countries, teacher PD is one component of a system with overall alignment and agreement between many different levels: policymakers, researchers, teacher educators, school management, and, more importantly, the teachers themselves [13].

For Borko et al. [14], the interest in this field is because the continuous professional development of teachers is one of the key factors for improving the education provided by schools. Consequently, most PD scholars consider it inextricably linked to any effort of educational reform or reform of teaching practices in line with current SE trends [5]. Based on the above, a crucial issue that arises concerns the way that teachers can learn more effectively when innovations in teaching are introduced. Most PD programs for in-service science teachers seek to increase teachers' learning concerning knowledge of relevant subject matter and appropriate teaching methods [13]. Additionally, to serve the purpose of teachers' learning, the teachers' educators employ a wide range of methods and produce a similarly wide range of effects [15]. Moreover, empowering teachers' learning relates to important parameters that any PD program should consider to be effective [8,13,16–19].

Darling-Hammond et al. [16], reviewing several papers, concluded that seven common characteristics are emerging in research relating to the effectiveness of professional development programs. These characteristics are as follows:

(a) *Focusing on specific content*. Programs aiming to familiarize participants with new teaching approaches need to focus on specific content. This ensures that participants make good use of the appropriate content to support teacher learning within the same school context in which they will use them.
(b) *Promoting teachers' active participation.* Teachers need to actively engage in designing and implementing new teaching approaches that will guide their students, e.g., interactive activities. The same authors [12] conclude that authentic experience of professional knowledge connected with school reality and implementation cannot be realized through traditional PD approaches such as lectures.
(c) *Promoting peer collaboration*. Effective PD programs encourage teachers to share ideas and motivate collaboration in the same way that they will need to with their students. In this way, modification of teachers' views and professional culture is more easily achieved.
(d) *Use of models and good practice examples*. Use of examples of good implementation practices helps teachers realize what they should be aiming for and how this could be achieved. Such examples can be teaching plans, samples of students' papers, observation of teaching, or study of recorded teaching sessions.
(e) *Provision of appropriate teaching support.* Providing specific knowledge and support for teaching content as well as implementation practices, based on teachers' needs on a personal basis, is considered an important factor in the program's effectiveness.

(f) *Feedback and reflection.* Creating opportunities and providing time for teachers' reflection and peer feedback is a common characteristic in PD programs empowering participants to reconsider practices and upgrade their teaching skills.
(g) *Time viability.* This aspect highlights that it is extremely important to provide sufficient time for teachers to gain new knowledge on a theoretical basis and then offer the opportunity to try these new methods and reflect on them without time pressure.

Most of these factors are also confirmed in a large-scale study by Doyle et al. [13] examining 231 PD programs, their specific characteristics and achieved results. Doyle et al.'s [13] study revealed that the following five characteristics proved to be critical for effective PD and teacher learning:

(a) Focus on content, including both subject matter content and how students learn that content;
(b) Teachers' active participation in learning during the program;
(c) Coherence between what is taught in the PD program, reforms and policies at the state and local levels, and teachers' prior knowledge and beliefs;
(d) A long duration of the program, including consideration of the number of days spent in the program, how spread apart those days are, and the amount of time (e.g., in hours) spent carrying out activities within the program itself;
(e) Collective participation of teachers of the same school, grade or department.

Finally, a general condition to produce effective professional development and learning is providing responsible management during PD. This management, which concerns the PD organizers, should consider both the trainers' and the participants' needs, e.g., by forming appropriate teaching material and a pedagogical framework to facilitate teaching and learning. A specific aspect of this framework, most often referred to in pedagogical and psychological research findings for science education, is the integration of practices that enhance inquiry learning and teaching [19]. According to these findings, teachers should be trained to include the main concepts of science education in their teaching, while at the same time, they should facilitate students to acquire necessary skills during inquiry implementation as an innovative method of teaching and learning.

The term inquiry refers both to the way scientists work and the activities through which students approach scientific concepts procedures and practices [19]. Inquiry is described in general by NRC [19], as a method that aims to highlight what is already known through experimentation and evidence, using data collection and analysis to interpret and suggest possible answers, provide predictions and explanations, and report research results. Additional terms and procedures used to describe inquiry are the use of research skills, seeking answers about certain science concepts using active ways, searching effectively for appropriate information, and evaluating it. For example, Luera and Otto [20] point out that inquiry teaching refers to learning activities through which students can develop knowledge and understanding of scientific ideas, as well as the understanding of how scientists study the natural world by setting scientific-oriented questions. Howes et al. [21] describe inquiry teaching as a teaching approach that helps students develop scientific skills and offers a deep understanding of the nature of science and its scientific content. The realization of inquiry in science classrooms could be differentiated between "inquiry as means", that is, inquiry as an instructional approach or pedagogy, and "inquiry as ends", that is, inquiry as a set of instructional outcomes for students [21,22]. In both perspectives, learning should happen within a problem-based inquiry process, and inquiry is defined as debating with peers, planning investigations, searching for information, using and constructing models, forming coherent arguments, etc. "Inquiry as ends" is further differentiated into two sets of outcomes, being well-documented, that students in grades 5–8 should develop: (a) abilities to perform scientific inquiry and (b) understandings about scientific inquiry [23].

Based on the above descriptions mentioned in the literature and research findings concerning science teaching, inquiry is suggested as an innovative teaching approach. Psillos [23] considers inquiry teaching as the cornerstone of the ongoing discussion of

education reform efforts in many countries. Vorholzer and von Aufschnaiter [24] also refer to inquiry as an important strategy in science teaching, which can serve multiple learning goals. Both researchers and teachers agree that inquiry implementation can be beneficial for students and learning. Inquiry advantages relate to motivating students to develop and use research skills, construct and interpret meanings for experiments or natural phenomena and acquire scientific knowledge in an active way, supporting long-term understanding of scientific knowledge and nature of science and positive attitudes towards science [25–27]. Aldahmash et al. [28], reviewing research trends in in-service professional development, sum up studies about inquiry and conclude that the inquiry method is particularly effective in terms of sustainable education and development, as it offers the necessary supplies for teachers and students to be actively involved in a lifelong process of learning and engagement in science.

The above are valid internationally, mainly in financially and educationally developed countries. In many countries, it is common ground that science teaching tends to focus more on conveying declarative knowledge (concepts, laws, principles, phenomena, etc.) rather than the way knowledge is produced and validated, such as the use of inquiry method in designing experiments, and research seeking information, modelling procedures, etc. Moreover, inquiry implementation in real classroom conditions seems to be limited to specific activities that can easily be fitted to the curriculum demands [29]. Many researchers have stressed the difference between theory and practice [25,30], and refer to the difficulties teachers usually have to face when they are challenged to adopt inquiry in classroom [25,29,31]. These difficulties may relate to both contextual (external) as well as internal (relating to teachers') reasons. Among external difficulties commonly mentioned are the lack of time, limitations of the curriculum, and material or infrastructure deficiencies. As internal factors commonly refereed to cause teachers' difficulties in the implementation of classroom inquiry, are the divergent interpretations on how inquiry should be implemented in class, teachers' beliefs about the nature of science, lack of inquiry experience leading to diffidence, and the fact that inquiry teaching requires multiple teaching skills, directing teachers to more guided inquiry practices, considered as more manageable [9,25,32,33]. Some of these conditions may likely be attributed to lack of teachers' proper training, resulting a low level of epistemological comprehension of science in the educational community [19,34]. That is why researchers in the science education field highly value the development of effective ways to disseminate inquiry procedures both among students [22] and teachers [34–37] at all levels of education.

In this paper, we study the effect of a PD program aiming to familiarize participants with current trends in science teaching (ST), putting emphasis on the inquiry approach. In particular, we study and compare science teachers' views and practices, both during and a year after the PD program, as a way of shedding light on the terms and conditions that may or may not affect primary and secondary teachers to undertake inquiry activities in everyday school practice. The study derives from a wider research project called Science Teachers Inquiry (STI). The project's main objective was to detect and recommend ways to empower inquiry practices among three different education groups.

2. The Research

2.1. Research Background

This paper studies changes in primary and secondary in-service teachers' views and practices following their participation in a 12-month-long PD program about the adoption of inquiry teaching approaches. These changes were recorded both during and a year after PD program completion. The particular PD program aimed to enrich school science effectively, through the familiarization of participants with current trends in ST, that include instructional design based mostly on guided inquiry regarding the preparation, conduction, and evaluation of out-of-school visits to science and technology sites. The PD included both theoretical training on current trends in ST and classroom implementation of inquiry activities. These activities were designed to prepare students for an out-of-school visit

and diffuse their inquiry findings to the local community [7]. In order to train teachers in instructional design and inquiry implementation, Teaching Learning Sequences (TLS) were selected as the most appropriate method [37]. The domains of PD training included inquiry teaching approaches, content transformation processes, issues related to procedural and epistemological knowledge, types of teamwork teaching (e.g., jigsaw), the use of models and modelling, the role of teachers' reflection on teaching effectiveness, and the incorporation of non-formal settings in science teaching [7]. The link of literature-based knowledge with everyday school practice was facilitated through the use of an inquiry-based TLS, which served as an example of good practice for the participating teachers. This already made example TLS of guided inquiry teaching evolved materials (e.g., conductors and isolators) used in telecommunications and included a site visit to a local communication provider, having a total duration of 10 teaching hours, organised in five teaching sessions. This TLS was studied, adapted, and applied by teachers participating in their own classes as an action research project [38]. As part of this project, during implementation, teachers also acted as researchers for their own students, studying the learning outcomes of their teaching designs and inquiry practices. Teachers reflected on these outcomes as part of their research; at the same time, this reflection was planned to facilitate their own learning during the PD. Finally, during the last phase of the PD program, participants were encouraged to design and implement their own inquiry teaching lesson plans, in collaboration with other teachers from the same PD program but from different educational levels (primary and secondary) [7]. Teachers' collaboration between peers is considered as an important factor contributing to the effectiveness of the PD [13,16]. In this case, the participants' interaction helped teachers' empowerment from both educational levels. Primary school teachers enriched their content knowledge thanks to their secondary colleagues' assistance, while the latter benefit more concerning pedagogy issues and classroom management, given the experience of the former. In this phase, teachers also acted as researchers of their students. Overall, the program was designed to meet conditions and characteristics related to effective inquiry PD as indicated in the literature [9,10,13,16].

2.2. Methodology

2.2.1. Research Question and Method

The research's purpose is to check and record whether the teachers that participated in the previously described PD program embrace inquiry-related views and have adopted any respective teaching practices a year after its completion. The research question guiding this study is as follows:

Which aspects of the inquiry approach do teachers apply a year after the PD program? This question is split into the following sub-questions:

(a) How have teachers' views and practices about inquiry teaching been shaped a year after their attendance of a PD program?
(b) Which aspects of inquiry approach that they have been familiarized with in the past are still integrated and implemented into their current science teaching?

To answer these questions, multiple case studies were selected as the most appropriate method. Case study research means conducting an empirical investigation of a contemporary phenomenon within in its natural context, using multiple sources of evidence, and may include several matters to be studied [39]. Case study is considered an in-depth qualitative method of education research attempting to inquire and describe in detail issues relating to the specific area of interest to be studied. It is also considered as an effective approach in education research because it allows researchers to study teachers individually (e.g., teacher characteristic identities, methods, teaching approaches, etc.) in real teaching conditions, while at the same time various aspects possibly affecting the live, complex, and dynamic environment of a school classroom can also be considered [40,41]. In this study, the research was focused on developing an in-depth understanding of the PD process of the participants by collecting both qualitative and semi-quantitative data [42] for teachers' views and practices through multiple sources of information (observation,

interviews, and reports) and for each participant [43]. This extensive information gathered for each participant is common in case studies for developing an overall understanding of each case/teacher in the delimited context of the research [44]. At the same time, action research was used as a commonly accepted method utilized in professional development aiming to broaden teachers' inquiry views and practices through specific actions [7]. Action research offers opportunities for possible modification of teaching attitudes and strategies through short-scale interventions where teachers act also as researchers co-developing, implementing, and evaluating their teaching design through continuous reflection [39,44].

The study combines elements from at least two research approaches/methods, namely case study and action research, each of them having a significant contribution to the overall research design. More specifically, it assimilates the case study approach, as the four participating teachers were treated as distinct cases, each one having different competences, needs and experiences, and researchers' guidance to them was adjusted to their individual professional profile. Moreover, our study adopts core elements and characteristics of action research, as researchers and teachers (during their teaching) adopted continuous planning, monitoring, feedback, adjustment and iteration of the teaching practice. This purposefully selected, literature-guided approach aimed to assess teachers' engagement during the PD program, and it is currently considered as an effective way of teachers' learning [7,9,13,16]. However, such an approach presents major differences compared to traditional in-service teachers' trainings, which were commonly used in the past but controversial in effectiveness [9,17].

2.2.2. Participants and Research Tools

The research was conducted in four schools in the Regional Unit of Florina, 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 teachers had 14–27 years of teaching experience, and had participated, a year earlier, in the previously described PD program, without having, in the meantime, any other long-term inquiry training.

Teachers' practices were recorded through a non-participatory observation approach, with at least two observers per teaching, using an observation protocol [7,45]. The protocol recorded the frequency of occurrence of different aspects of inquiry (e.g., inquiry implementation in general, guided inquiry, open inquiry, etc.). Each aspect of inquiry (e.g., open inquiry) was assessed through multiple sub-questions, each one recording a distinct and specific inquiry practice (e.g., "The teacher poses questions to encourage students' inquiry"). The frequency in which each of these inquiry practices (sub-questions) occured was scored using a three-point scale (1 = rarely, 2 = sometimes, 3 = usually) producing semi-quantitative data [31]. Moreover, in the observation protocol, for every aspect of inquiry, an additional field for free text was included, in which descriptive evidence/examples of the specific inquiry practice was required from the observers, in order to justify their score in the closed-form questions assessing the same inquiry domain (qualitative data). To ensure credibility, the protocol was completed by two independent observers for each teacher and each teaching session, enabling counterchecks. In case of contradictions, observers discussed frequencies and supporting data (audio files) to reach a common agreement.

Teachers' views about inquiry were recorded in each research phase by (a) a pre-teaching questionnaire, (b) teachers' diaries during implementation, and (c) a semi-structured interview after their teaching sessions. The use of multiple tools for recording teachers' views enabled the triangulation of data and thus ensured research validity [44,46]. The pre-teaching questionnaire was structured, comprised of two sections, aiming to provide information about teachers' views regarding inquiry approach in general, and about how they personally implement inquiry into their classroom. The first section was scored using a Likert-type scale, which is a suggested way to incorporate a degree of sensitivity and differentiation of participants' responses, while also providing quantitative data [44]. The second section included open-ended questions, allowing in-depth research through

personal explanations of participants regarding possible factors affecting their views [44]. Additionally, a second research tool, a structured teaching diary form, guided teachers to keep notes and encouraged their reflection on how they implemented their inquiry teaching design concerning, e.g., content or group work, etc., for every teaching session. Finally, semi-structured reflective interviews were also used to record teachers' inquiry views after teaching observation. Interviews are a commonly used method in educational research, allowing deeper and more enlightening insights into specific areas of interest [44]. The interviews consisted of eight (8) questions focusing on the teaching design and method, possible difficulties teachers might face, etc. (e.g., what factors did you consider in your teaching design?). Depending on teachers' answers, follow-up questions were asked, aiming to better clarify their views, e.g., "Why do you say that?" or "Can you give us an example?".

All these tools used to assess teachers' views and practices had been developed during the PD, and the same were implemented during the PD program (Phase 1), and one year after its completion (Phase 2). However, in Phase 2, due to usual changes in school life, not all teachers taught at the same grades or schools as they had been teaching during the PD program (Table 1). In addition, as seen in Table 1, the topics of teaching also differentiated between the two observation phases (Phase 1 and Phase 2). Thus, during Phase 1 (during the PD), all teachers covered the topic of energy production through renewable and non-renewable energy sources. More specifically, they designed activities as part of the preparation of a site visit to (a) a lignite-fuelled local power station plant, and (b) an environmental education centre. The total duration of the planning was ten (10) teaching hours (five sessions) for each teacher. During Phase 2 (1 year after PD), each teacher was observed for a period of four (4) to six (6) teaching hours, during their teaching on a science topic that they had selected.

Table 1. Participants, grades, and topics of teaching in each research phase.

Participants	Phase 1 (during PD)		Phase 2 (1 Year after PD)	
	Grade	Topic of Teaching	Grade	Topic of Teaching
Teacher 1 ***(primary)***	6th	Energy Production, Renewable and non-renewable energy sources	6th	Electric circuits
Teacher 2 ***(primary)***	5th		1st	States of matter (gas/liquids/solids)
Teacher 3 ***(secondary)***	9th		11th	Ohm's Law
Teacher 4 ***(secondary)***	9th		9th	Electromagnetism

2.2.3. Data Analysis

Data regarding teachers' practices were collected through the observation protocol with a three-point scale (1 = rarely, 2 = sometimes, 3 = usually). These semi-quantitative data were elaborated in a semi-quantitative way to assess the overall teachers' inquiry frequency of practices by calculating their approximate concentrations [7]. In particular, the frequency of inquiry practices (semi-quantitative data) was calculated as the average occurrence of each distinct inquiry practice (i.e., protocol sub-question) in each classroom observation. These averages were calculated for each research phase (during and after the program), and for each teacher. These inquiry practices were grouped together based on the various aspects of inquiry they represent (e.g., open inquiry, guided inquiry, etc.). The average occurrence of these aspects of inquiry was also calculated for each phase (1 and 2) and for each teacher.

Additionally, qualitative data from the observation protocol, deriving from the specific field with descriptive evidence/examples of the specific inquiry practice implementation in class, were examined by two independent researchers. This procedure was conducted for confirmation reasons to ensure that the specific average frequency was representative of the teaching approach adopted in class, e.g., the assigned frequency of 2.5, during a

teaching session, regarding the "*Adoption of any kind of inquiry approach*", was based on the following information unit that accompanied the descriptive evidence: "*Teacher aks students to search written or inline sources and report which materials have magnetic properties*". Another characteristic example confirming that guided inquiry practices with the maximum average frequency of 3 in the three-point scale used wasthe following information unit: "*Students are assigned to a specific activity through a working sheet in order to find out which of the available materials in their group supplies can be used to provide a parallel connection at an electric circuit (metallic pins, rubbers, pencils, fossil paper etc.)*". On the other hand, an example for guided inquiry practices is described in the following information unit provided by the descriptive evidence: "*Students follow the teacher's instruction to organize their investigation in order to fill in the answers from the working sheet*".

Consequently, to be able to draw safe conclusions about teachers' practices during and after the program, the need to characterize the occurring frequency of each inquiry practice emerged. For both time periods (during the PD and 1 year later), two types of practices were recorded, pursued and complex. Pursued practices were considered practices of an innovative character that incorporated actions introducing, facilitating, or enhancing inquiry, e.g., "*Teacher rephrases student's questions in order to encourage inquiry*". *Complex* practices were considered practices that could include actions facilitating both innovative types of teacher or student engagement during teaching as well as actions of a more traditional character, such as "*the teacher having a dominant role during experimenting*" or "*teacher sets the questions*". These complex elements are quite common during periods of time in which teachers try to adjust and incorporate new teaching strategies/approaches into their repertoire [7,16].

For pursued practices concerning inquiry implementation, frequencies that noted scores:

- Between 1 and 1.5 were characterized *as mixed* since they covered a range of 25% of the used scale (scale range: 1 to 3, 0.5 out of 2 results in 0.25, which is actually a percentage of 25%);
- Between 1.51 and 2 was characterized *as relative innovative* since they covered an additional range of 25% of the used scale (scale range: 1 to 3, 0.5 out of 2 results in 0.25, which is actually a percentage of 25%);
- Between 2.1 and 3 was characterized *as innovative* since they covered a range of 50% of the used scale (scale range: 1 to 3; 1 out of 2 is a percentage of 50%).

The use of unequal ranges at the above ranking of characterizing practices is due to the fact that the contained sub-questions are formed in a way that mainly records pursued/innovative types of practices instead of traditional ones. In particular, scores higher than the median of the used scale (2 = sometimes) indicate that recorded implemented practices were indeed clearly innovative, while scores lower than the median (2) may indicate the simultaneous occurrence of both less innovative (frequencies between 1.51 and 2) and possibly more traditional (frequencies between 1 and 1.5) types of practices.

To characterize *complex practices* (possibly including both innovative and traditional teaching actions), differences between the recorded frequencies of the two contradictory and/or co-occurring practices were measured and compared. Thus:

- Score differences lower than 0.40, meaning 20% deviation in the two-grade scale used (0.40/2 = 0.2), were indicative of characterizing the practice as mixed (meaning equally traditional and innovative);
- Score differences between 0.41 and 0.80, suggesting a considerable deviation of 21–40%, were indicative of characterizing the practice as relatively innovative or relatively traditional;
- Score differences higher than 0.81, suggesting important deviation between practices, were indicative of characterizing the practice as explicitly innovative or traditional, depending on which practice was, respectively, dominant (innovative or traditional).

Finally, frequencies of teachers' inquiry practices during the professional development project were compared with those one year after its conclusion, and this was the case for both types of practices, pursued and complex.

The characterization of teachers' views was produced through the content analysis [46] of the units of meaning found in each research tool (written diaries and interview transcripts) and were classified into three different categories depending on their content. Units of meaning that expressed traditional elements about teaching, strong reservations about inquiry implementation, or obstacles were characterized as traditional, e.g., "*teacher preparation and time limits are a deterrent for adopting inquiry*". Information units expressing a positive attitude about inquiry and a tendency of redefining traditional teaching approaches were characterized as innovative, e.g., "*I feel like I am more motivated and capable to implement inquiry in a more frequent base*" *(Teacher 2).* For characterizing teachers' views, the number of units of meaning from each category (traditional or innovative) was compared. When one category outnumbered the other by at least one information unit, views were characterized, respectively, as traditional or innovative. In case there was an equal number of units of meaning from both categories, without any distinct orientation, views were characterized as mixed. The first author classified the information units into the aforementioned categories, and two of the remaining authors served as reviewers in order to increase the reliability of the process.

3. Results

Data analysis concerning the adoption of any aspect of the inquiry approach highlighted the overall long-term effect of the professional development program on three out of four science teachers' practices. As seen in Table 2, Teacher 1 (primary education) further embraced the adoption of inquiry approach in general during science teaching (increased from 2.76 to 2.94), while Teacher 2, also from primary education, preserved the innovative character in her teaching approach, although the average score for this specific practice, one year after the program's completion, was slightly lower (dropped from 2.50 to 2.10). This reduction can be attributed to the fact that Teacher 2, during Phase 2, did not include in her teaching design the aspect of research in either printed or electronic sources. This was purposefully decided by her, as at her observation during Phase 2, she was teaching first grade, and her students had just acquired basic skills of reading and writing. Thus, her teaching plans were mostly based on hands-on activities, aiming to make sensory distinctions of properties between different forms of matter and their classification.

Table 2. Teachers' views and practices regarding the adoption of ANY KIND OF INQUIRY approach.

Adoption of Any Kind of Inquiry Approach		Teacher 1	Teacher 2	Teacher 3	Teacher 4
Phase 1	Average of Practices	2.76	2.50	1.8	2.28
	Characterization	Innovative	Innovative	Relative Innovative	Innovative
Views characterization		Innovative	Innovative	Innovative	Innovative
Phase 2	Average of Practices	2.94	2.10	2.75	1.50
	Characterization	Innovative	Innovative	Innovative	Mixed
Views characterization		Innovative	Innovative	Innovative	Innovative
Practices modification		Stability	Stability	Improvement	Regression
Views modification		Stability	Stability	Stability	Stability

Additionally, Teacher 3 (secondary education) also noted progress in the adoption of any kind of inquiry approach, compared to her initial average during Phase 1 (from 1.83 to 2.75). In this case, Teacher 3, during Phase 2, designed a short-time teaching sequence aiming to guide eleventh-grade students, through experimental activities in the school's

physics laboratory, to electric circuits connected in line and/or in parallel, to formulate Ohm's law. Teacher 4, on the contrary, while achieving innovative practices concerning the adoption of the inquiry approach during the PD program (2.28), during Phase 2, faced difficulties in the implementation of such innovative practices, which led to a lower occurrence average on the specific practice and, thus, she presented regression.

In relevance to teachers' views on the adoption of any kind of inquiry practices, analysis indicated that their positive attitudes during the PD program, towards inquiry, did not change one year after the end of it. Secondary teachers, for example (Teachers 3 and 4), stated that "when designing their own teachings plans, they have the opportunity to choose content, based on their students' life experiences and interests, and this resulted in more active student participation". Primary teachers also expressed their appreciation for the approach and stated that they "try to find or create opportunities for inquiries throughout the year, especially when the suggested content defined by the curriculum can be well supported through inquiry".

Regarding practices related to guided inquiry, all teachers showed stability or even improvement in their performance. As seen in Table 3, both primary school teachers (Teacher 1 and 2) preserved their guided inquiry practices acquired during the PD program, long after its conclusion. Teacher 3 (secondary teacher) managed to further support guided inquiry teaching (from 1.92 to 2.10), while Teacher 4 (secondary teacher) implemented guided inquiry practices with a slight regression, which, overall, did not substantially alter the innovative element of her teaching approach (which slightly dropped from 2.31 to 2.00).

Table 3. Teachers' practices and views regarding aspects of GUIDED INQUIRY.

Guided Inquiry Practices		Teacher 1	Teacher 2	Teacher 3	Teacher 4
Phase 1	Average of Practice	2.25	2.25	1.92	2.31
	Characterization	Innovative	Innovative	Relative Innovative	Innovative
Views characterization		Innovative	Innovative	Innovative	Innovative
Phase 2	Average of Practice	2.33	2.50	2.10	2.00
	Characterization	Innovative	Innovative	Innovative	Relative Innovative
Views characterization		Innovative	Innovative	Innovative	Innovative
Practices modification		Stability	Stability	Improvement	Regression
Views modification		Stability	Stability	Stability	Stability

Furthermore, teachers' views towards guided inquiry remained encouraging about its implementation. Primary teachers claimed that "when students are engaged regularly with guided inquiry activities, they gain confidence and become more competent, and this encouraged teachers to seek opportunities for designing inquiries when time and content conditions were convenient". At the same time, their secondary colleagues noticed that "when students are engaged with experimental, hands-on activities during science classes, they are more enthusiastic about learning science, and this interest motivates and helps them develop their science knowledge".

The situation is slightly different as far as more open inquiry practices are concerned. The results presented in Table 4 show that three out of the four teachers, both during the professional development program and one year after its completion, found it hard to incorporate more open inquiry activities into their teaching design. Besides that, it is evident that Teacher 1's practices differentiate in this part of the inquiry range. More specifically, Teacher 1 included, as an important part of his teaching design, a more open activity challenging students to find possible ways to illuminate different parts of a mock-up wooden house, using a variety of everyday materials (e.g., wood, spoons, aluminium foil, clippers, gum, etc.) available in class.

Table 4. Teachers' practices and views regarding aspects of open inquiry.

Open Inquiry		Teacher 1	Teacher 2	Teacher 3	Teacher 4
Phase 1	Average of practice	1.0	1.00	1.30	1.30
	Characterization	Mixed	Mixed	Mixed	Mixed
Characterization of views		Innovative	Innovative	Innovative	Innovative
Phase 2	Average of practice	2.00	1.00	1.00	1.00
	Characterization	Relative Innovative	Mixed	Mixed	Mixed
Characterization of views		Innovative	Innovative	Innovative	Innovative
Practices modification		Improvement	Stability	Stability	Stability
Views modification		Stability	Stability	Stability	Stability

As can also be seen in Table 4, teachers' views about open inquiry practices maintained their innovative character. For example, Teacher 1 (primary) stated that he purposefully chose the specific teaching plan because he thought "it would be an interesting experience for both students and researchers to find out how an activity less guided and much closer to the open end of the inquiry range could work out". At the same time, qualitative data about teachers' views contained units of information that were indicative of the challenges teachers face in relation to open inquiry approaches.

For example, Teacher 3 (secondary) expressed her interest in "gaining knowledge about how to implement more open inquiry teaching" and that she "would like to see an example of an open inquiry in class, and it would be extremely interesting to introduce us to ways that we could include - emphasis on prediction during open inquiries". Teacher 2 (primary), on the other hand, referred to the "fear of losing control of class and of the teaching flow" to explain why she considers guided inquiry a more safe and fruitful approach than others.

A last but important aspect of inquiry practices examined was the way inquiry activities and conclusions are summarized during the closure of teaching. In this case, this aspect of inquiry was considered complex because both innovative (dominant students' role) and traditional practices (dominant teachers' role) could be recorded. Thus, results for this aspect of teaching could provide more clear information about the intensity of student engagement and participation during summarizing.

Teachers' summarizing practices are provided in Table 5. Based on this, it is indicated that during Phase 1, in primary education teachers' classes (Teachers 1 and 2), students' role in summarizing is considered as a pursued practice, and it was dominant at an innovative (Teacher 1) and relatively innovative level (Teacher 2). On the other hand, in the case of Teacher 3 (secondary), the teacher's role was dominant (relative traditional practices), while for Teacher 4 there was equal participation for both teacher and students (mixed practice). In Phase 2, a year after the PD, the situation is slightly different. All teachers present, to some extent, regression in this domain of inquiry. Students' summarizing, an innovative practice, is still dominant for Teacher 1, but with a much lower frequency than in the previous phase. Teachers 2 and 3, during phase 2, presented mixed practices in comparison to their relative innovative approaches in Phase 1.

Table 5. Teachers' practices during the summary of inquiry teaching.

	Summarizing	Teacher 1	Teacher 2	Teacher 3	Teacher 4
Phase 1	Teacher Summarizes (TS1)	1.60	2.00	2.20	2.00
	Students' Summarize (SS1)	2.50	2.50	2.00	2.00
	Difference SS-ST	**0.9**	**0.5**	**−0.20**	**0.00**
	Dominant Practice	**Innovative**	**Relative Innovative**	**Relative Traditional**	**Mixed**
Phase 2	Teacher Summarizes (TS2)	1.50	1.80	1.80	1.80
	Students' Summarize (SS2)	2.00	2.00	2.00	1.00
	Difference SS-TS	**0.50**	**0.20**	**0.20**	**−0.80**
	Dominant Practice	**Innovative**	**Mixed**	**Mixed**	**Relative Traditional**
Difference SS-TS (Phase 2–Phase 1)		**−0.40**	**−0.30**	**0.40**	**−0.8**

Teacher 4, in this second phase, made all the summaries, and students' participation was recorded at the lowest frequency level of the scale (1 = rarely). In the last line of Table 5, a comparison between the average practices (innovative and traditional) of summarizing teaching is presented, showing that, in all cases, teachers noted a setback concerning this aspect of inquiry implementation during phase 2.

4. Discussion

The results on the adoption of some kind of inquiry approach, as well as the adoption of guided inquiry one year after the programs' completion, compared to those during the PD program, are very encouraging, showing that teachers, despite minor differentiations, effectively established inquiry practices into their science teaching and in different contexts. Several research findings concerning characteristics of effective PD programs reviewed by Capps et al. [9] highlight the importance of supporting teachers in developing their own inquiry-based teaching and engaging them in authentic research experiences as the "missing link" in helping teachers enact inquiry-based instruction in their own classrooms. In this study, the results provide evidence that the PD program established teachers' inquiry both as theoretical knowledge and as a practice, in order to stabilize change in teachers' practices when opportunities for innovative teaching arise in a real classroom setting [9,47]. Based on the literature, the incorporation of inquiry approaches is also related to conditions ensuring teachers feel comfortable to enact them in class. These conditions are developed when they have had positive inquiry implementation experiences [48] as the ones acquired during the PD program. The PD program's design proved to fit the seven characteristics of effective professional development reviewed by several studies [13,16], enabling teachers to engage actively with inquiry in real classroom conditions for a sufficient period of time, making use of good practice examples and gaining valuable feedback on their teaching. Participants highlighted that the PD included them as co-formers and took into account their opinions for procedures, encouraging them to develop, evaluate, and modify inquiry teaching designs both of their colleagues as well as their own. This adoption was made according to their personal teaching profile and their students' needs, was helpful, and empowered them to gradually obtain the desired teaching experience. As highlighted by research [11–13], teachers voices need to be heard and considered because their views are a significant component that can facilitate the PD effectiveness. Studies [47,49,50] have shown that teachers feeling efficient in designing and coordinating inquiry procedures present less anxiety and are thus more likely to implement inquiry approaches in their class and in a more effective way. This "knowledge of practice" [31], produced and used during the PD program, proved to be valuable for teachers as it facilitated understanding of how to implement inquiry-based instruction in their own classes a year after the program's completion [9,49,51].

Although guided inquiry as a practice entrenched or was even further enhanced during Phase 2 for most teachers, open inquiry approaches remained mainly inactive, as mentioned in the previous section. This could be easily attributed to the fact that participants were not gradually acquainted with more open inquiry practices during the PD, as they did in the case of guided inquiry. Guided inquiry teaching design was the central focus of the given good practice example, which was studied, modified, and implemented during the program. Other research findings [29] also provide evidence that this lack of previous experience on more open inquiry practices may play a crucial role, preventing teachers from the adoption and implementation of such practices into their classes. Moreover, most of the teachers who participated in the research had to coordinate and support inquiry teaching plans in quite crowded classes, with many students—a common condition in rural school areas. According to other studies [33,52], these types of classes tend to raise major challenges in classroom management, which are not easily addressed by a single teacher, especially when they attempt to implement open inquiry. A lack of open inquiry teaching experience as well as teachers' concerns about granting wider student autonomy and losing classroom and learning control of their students are elements that research has already identified to increase teachers' stress and unwillingness to attempt more open inquiry activities [51].

As far as practices related to the summarizing of inquiry teaching are concerned (e.g., drawing conclusions in the end of teaching), results highlight the fact that student's participation, during the PD program, presents a wide variation between teachers from different educational levels (primary and secondary), while such variation was also recorded between the duration of the program and one year after it. Besides Teacher 1, who remained stable, giving space and time for students to summarize teaching both during and 1 year after the PD, all other teachers present mixed or even relative traditional practices after the PD. Other studies [53–56], trying to clarify the type and extent of inquiry implementation through teacher's and student's participation, suggest that many teachers' individual characteristics, such as personal motives, previous experience, or their self-notion of classroom management, may play an important role. Although there is common agreement that guided inquiry practices are considered to provide teachers a large degree of control, there is also evidence that students' engagement can be substantially enhanced, depending on the specific goals set by the teacher [21]. In our study, time pressure, given the limited available time for observation during Phase 2, compared to Phase 1, along with different students' age and competences (e.g., first-grade primary school students for Teacher 2), possibly affected students' role during the summarizing procedure. These contextual factors are important, and the reality is that there is no classroom environment, student group or teacher reaction that is identical [9].

5. Conclusions

Our research findings are encouraging since participating teachers managed to incorporate and strengthen guided inquiry practices into their teaching. The research showed that when teachers possess in-depth science content knowledge, understand what inquiry is, and have experience in using inquiry-based teaching approaches, they can respond effectively to the demands of current trends in science education. Allowing sufficient workshop time for teachers to adapt their lessons plans to be congruent with inquiry-based instruction, discuss their ideas and concerns with colleagues and professional trainers will more likely ensure that teachers will feel comfortable enacting reformed-based inquiry curriculum in their classrooms [9,57]. Gradually granting student autonomy, carefully choosing the appropriate cognitive load that students can manage, and adjusting content to the specific teaching objectives posed by the teachers [27] prove to be core parameters for effective inquiry implementation for both teachers and students.

Familiarizing teachers with guided or more open inquiry approaches requires valuable experience gained through the step-by-step training of teachers to form the appropriate teaching design and supporting them to implement it to real classroom conditions [33,51].

Moreover, teachers need to be trained and empowered to all kinds of guidance by gradual teaching scaffoldings, helping them to effectively face possible in-classroom challenges and build their teaching competence [51]. Open inquiry implementation needs even more systematic, consistent and long-term teacher empowerment in aspects of conceptual and procedural professional knowledge that challenges even the most inquiry-experienced teachers.

Encouraging results derived from this research provide evidence that it is possible for consciously involved teachers to enhance or modify their practices through PD programs. Since PD providers cannot directly control what motivates a participant to attend actively and engage creatively, they can tailor how they attract, recruit, and keep participants engaged in the learning process [13]. The need for greater cooperation between decision makers/policyholders of education and science teachers regarding professional development has also been noted in previous studies [57]. Based on our findings, it is important that science teachers' needs and views are taken into consideration when developing a PD procedure, aiming to diffuse innovative teaching methods. As mentioned in several other studies [8,13,16,17,19], our conclusions suggest that future PD programs should take into consideration the specific characteristics that play a crucial role contributing to the PD's effectiveness. These characteristics include the focus on specific content and offer of adequate time for teachers to participate actively and co-form their teaching designs with respect to their own and their students' learning needs. Additionally, the use of good practice examples may give a clearer view on what teachers should focus on and the possible ways they can achieve it. This could be considered as part of a wider significant factor, which is the offer of personalized and targeted support and feedback to participants, side by side. Teachers are offered the chance to try new things in the classroom as a trial-and-error process, in an attempt to reflect on and consequently redefine their practices.

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