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Influence of an Inquiry-based Professional Development on Science Teachers' Orientations to Teaching Science

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ABSTRACT
Inquiry-based instruction has been promoted worldwide to achieve scientific literacy among citizens. This kind of reform-based instruction requires science teachers to have specialized knowledge called pedagogical content knowledge (PCK) for teaching science, which includes a set of knowledge and beliefs. Orientations to teaching science are considered as an overarching component, which shapes and are shaped by the other components of PCK. This mixed-methods research aims to investigate the influence of an inquiry-based professional development on 67 science teachers' pedagogical orientations. Both quantitative and qualitative data were collected before and after the professional development, using a contextualized pedagogical orientation test with multiple-choice questions and written formats. The quantitative data were analyzed using Mann-Whitney U test, while the qualitative data were analyzed using content analysis. The quantitative results reveal a positive change in the science teachers' orientations towards inquiry-based instruction. However, the qualitative results suggest that this change occurred only in the particular context where the science teachers focused more on students' learning than on the instructional objectives and classroom management issues. Thus, what and how students can learn in the context of inquiry-based instruction should be emphasized in the professional development for science teachers to adopt inquiry-based orientations.

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Introduction

Inquiry-based instruction has been promoted worldwide to achieve scientific literacy among citizens (Abd-El-Khalick et al., 2004). This kind of reform-based instruction requires science teachers to have specialized knowledge, known as pedagogical content knowledge (PCK) for teaching science (Abell, 2008). According to Magnusson et al. (1999), PCK for science teaching consists of five components of knowledge and beliefs regarding inquiry-based instruction: (1) knowledge and beliefs about the purposes and goals of teaching science; (2) knowledge and beliefs about science curricula; (3) knowledge and beliefs about the assessment of scientific literacy; (4) knowledge and beliefs about instructional strategies; and (5) knowledge and beliefs about students' understanding. The first component is termed for short as orientations towards teaching science (Magnusson et al., 1999), science teaching orientation (Friedrichsen & Dana, 2005), or pedagogical orientations (Ramnarain & Schuster, 2014), which can shape and be shaped by the other components as science teachers develop PCK (Park & Chen, 2012).

Regardless of the terms, orientations to teaching science are considered an overarching component of PCK. According to Gess-Newsome (2015), orientations to teaching science can act as situational amplifiers or filters as science teachers gain experiences regarding science teaching and develop PCK for science teaching. On the one hand, Eick and Reed (2002) have found that preservice science teachers with a strong pedagogical inquiry orientation benefitted from supportive experiences in science teacher education that emphasize inquiry-based instruction. On the other hand, Friedrichsen et al. (2009) have found that science teachers' pedagogical knowledge was filtered through their didactic orientation, as their instructional strategies were based on providing information to students. Given the important role of science teaching orientations in developing PCK for inquiry-based science instruction, researchers have devoted their efforts to investigating and facilitating inquiry-based orientations for science teachers.

Research has demonstrated that science teachers might begin their professional lives with didactic orientations to teaching science (Friedrichsen et al., 2009; Kind, 2016), with the goal of "transmitting the facts of science" (Magnusson et al., 1999, pp. 100–101) through the use of lecture-based instruction. The existence of didactic orientations can be explained using a sociological perspective, in that science teachers have personally constructed pedagogical orientations as a result of cognitive apprenticeship (Lortie, 1975) where they have observed their own science teachers' lecture-based practices of teaching science (Ladachart, 2011). As a consequence, such didactic orientation tends to act as a filter rather than an amplifier when science teachers gain supportive experiences regarding inquiry-based instruction through teacher education programs or professional development. Thus, it seems crucial that science teachers are facilitated to have inquiry-based orientations to teaching science before and/or during their development of PCK for inquiry-based science instruction.

There could be many possible ways to facilitate science teachers' inquiry-based orientations to teaching science. Based on Friedrichsen et al.'s (2011) theoretical proposal, orientations to teaching science can be defined as a set of beliefs with three dimensions, namely: (1) goals and purposes of science teaching, (2) views of science, and (3) beliefs about science teaching and learning. Given these dimensions, professional development can enable science teachers to have inquiry-based pedagogical orientations by helping them to understand scientific literacy as the key goal of science teaching, to have informed views on science, and/or to possess strong beliefs about inquiry as a way to teach and learn science. These implications are supported by Avraamidou (2013), who found that some experiences in science teacher education courses, such as inquiry-based investigations and discussions on contemporary theories of learning, outdoor field studies, a friendly classroom environment and the characteristics of their instructors can potentially shape science teachers' orientations toward inquiry.

Following this line of implications, this research aims at investigating the influence of an inquiry-based professional development on Thai science teachers' pedagogical orientations. It is important to note that, while research demonstrates that inquiry-based experiences can shape science teachers' orientations toward inquiry, it is not clear how such experiences could make a positive change in science teachers' orientations to teaching science, especially when considered from the three dimensions as proposed by Friedrichsen et al. (2011). For example, science teachers improve their orientations to teaching science as a result of inquiry-based experiences either because they better understand the goal of science teaching, or because they have more informed views of science, or because they develop better conceptions of teaching and learning. In other words, it is not clear which characteristics embedded in inquiry-based experiences influence science teachers to adopt more inquiry-based pedagogical orientations. It is this issue which the current research aims to address.

Literature Review

The concept of pedagogical orientations can be traced back to Shulman (1986), who introduced the notion of PCK as a specialized form of "subject matter knowledge for teaching" (p. 9, italics in original). Shulman (1987) provided seven categories of the knowledge base for the teaching profession, consisting of: (1) content knowledge, (2) general pedagogical knowledge, (3) curriculum knowledge, (4) PCK, (5) knowledge of learners, (6) knowledge of educational contexts, and (7) knowledge of educational ends, purposes, and values. Grossman (1990) elaborated on these categories of teacher knowledge by classifying them into four groups, namely: (1) subject matter knowledge, (2) general pedagogical knowledge, (3) PCK, and (4) knowledge of context. It is important to note that while Shulman (1987) has listed PCK as a distinct kind of knowledge at the same level as curriculum knowledge, knowledge of learners, and knowledge of educational ends, purposes, and values, Grossman (1990) has integrated these three kinds of knowledge as part of PCK. As a consequence, Grossman's (1990) model of teachers' PCK includes four kinds of knowledge, that is: (1) conceptions of purposes for teaching subject matter, (2) knowledge of students' understanding, (3) curricular knowledge, and (4) knowledge of instructional strategies.

Based on Grossman's (1990) model, Magnusson et al. (1999) have proposed a model of PCK for science teaching which includes five components, that is: (1) orientations to teaching science, (2) knowledge of science curricula, (3) knowledge of the assessment of scientific literacy, (4) knowledge of students' understanding of science, and (5) knowledge of instructional strategies. In this model of PCK for science teaching, the term "orientations to teaching science" is explicitly introduced, by which Magnusson et al. (1999) mean "knowledge and beliefs about the purposes and goals for teaching science at a particular grade level" (p. 97). This term is equivalent to what Grossman (1990) has referred to as conceptions of purposes for teaching subject matter. Moreover, it is highlighted that orientations to teaching science represent an "overarching" component that interacts with the other four components. The overarching position in the model indicates that orientations to teaching science plays a crucial role in shaping each component of PCK and thereby PCK itself.

Magnusson et al. (1999) have also provided a list of nine kinds of orientations to teaching science, namely: (1) process, (2) academic rigor, (3) didactic, (4) conceptual change, (5) activity-driven, (6) discovery, (7) project-based science, (8) inquiry, and (9) guided inquiry. However, it has been argued that some of these orientations to teaching science might not be supported by empirical studies with science teachers (Friedrichsen et al., 2011). As a consequence of this argument, some studies have aimed to identify orientations to teaching science as reflected by science teachers. For example, Kind (2016) has confirmed five of them, namely didactic, academic rigor, activity-driven, conceptual change, and inquiry. In a similar vein, Faikhamta (2013) has confirmed project-based science, process, guided inquiry, activity-driven, and discovery. Nonetheless, it has been cautioned that these orientations to teaching science can overlap and one science teacher may have more than one orientation to teaching science (Friedrichsen & Dana, 2005).

Friedrichsen et al. (2011) have argued that research on science teachers' PCK has often used orientations to teaching science as a theoretical concept in different or unclear ways because of a lack of understanding of its nature. On the basis of a critical review, they have proposed three dimensions for orientations to science teaching, which comprise: (1) the goals and purposes of science teaching, (2) views of science, and (3) beliefs about teaching and learning. While this proposal is supported by some studies in that experienced science teachers have expressed consistency among their views of science and their conceptions about teaching and learning science (Tsai, 2002), this may not be the case especially for preservice science teachers. Kind (2016) has noted that only five of 20 preservice science teachers with informed views of science expressed inquiry-based orientations to teaching science. This result makes the proposal about three dimensions of orientations to teaching science questionable. Thus, more research is needed to elaborate the nature of orientations to teaching science.

Some research studies suggest that orientations to teaching science are context dependent. For example, Ramnarain and Schuster (2014) have explored orientations to teaching science among two groups of science teachers working in different school contexts. The results indicated that science teachers at disadvantaged township schools tend to have more didactic orientations to teaching science, while those at suburban schools tend to exhibit more inquiry-based orientations to teaching science, leading to a conclusion that differences in science teachers' orientations to teaching science could result from contextual factors such as class size, availability of resources, time constraints, school culture, and parental expectations. In a similar vein, Nargund-Joshi et al. (2011) have found that science teachers' inquiry-based orientations to teaching science can be limited by an examination-driven educational culture. Thus, an investigation of science teachers' orientations to teaching science should not ignore the impact of the context on the minds of science teachers.

Given the fact that science teachers' orientations to teaching science may be multifaceted (Friedrichsen et al., 2011) and context dependent (Ramnarain & Schuster, 2014), their orientations to teaching science may be too complex to be assigned to one specific type. Thus, some researchers may describe individual science teachers' orientations to teaching science in order to illustrate this complexity (Friedrichsen & Dana, 2005; Nargund-Joshi et al., 2011). However, a detailed analysis of individual science teachers' orientations to teaching science can be time-consuming and laborious (Friedrichsen & Dana 2003), leading to a limitation if a study aims to investigate a large number of science teachers' orientations to teaching science. As the central goal of science education is to promote scientific literacy among citizens via inquiry-based instruction (Abd-El-Khalick et al., 2004), assessing science teachers' orientations to teaching science can and should be done with respect to their consistency with scientific inquiry as the recommended teaching practice of science education reform.

In attempts to overcome the limitations of research being time-consuming and laborious when assessing a large number of science teachers' orientations to teaching science within a certain period of time, Cobern et al. (2014) developed a contextualized, multiple-choice assessment of orientations to teaching science, which can be classified into four types of orientations, namely didactic direct, active direct, guided inquiry, and open inquiry. This classification system is in accordance with how science education researchers organize the levels of inquiry-based instruction, that is, confirmation inquiry, structured inquiry, guided inquiry, and open inquiry (Banchi & Bell, 2008), which is consistent with scientific inquiry as recommended by science education reform. Moreover, the four types of orientations to teaching science as identified by Cobern et al. (2014) were considered more appropriate because of the inclusion of the "didactic direct" orientation which, despite not being inquiry-based, is still common in Thailand (Faikhamta & Ladachart, 2016) where the current study was conducted.

Regardless of how orientations to teaching science are measured, research in this area has focused on both preservice science teachers (Avraamidou, 2013; Brown et al., 2013; Demirdöğen, 2016; Demirdögen & Uzuntiryaki-Kondakçi, 2016; Eick & Reed, 2002; Guven et al., 2019; Kind, 2016, Ladachart, 2020) and in-service science teachers (Faikhamta, 2013; Friedrichsen & Dana, 2005; Friedrichsen et al., 2009; Mavuru & Ramnarain, 2018; Nargund-Joshi et al., 2011; Park & Chen, 2012; Park & Oliver, 2008; Ramnarain & Schuster, 2014; Ramnarain et al., 2016; Suh & Park, 2017). However, with a methodological concern, these studies have mostly been exploratory or retrospective with a lesser number investigating the influence of an intervention on science teachers' pedagogical orientations (Demirdögen & Uzuntiryaki-Kondakçi, 2016; Faikhamta, 2013; Suh & Park, 2017). Moreover, these interventional studies used qualitative methods. Thus, quantitative research examining a change in science teachers' orientations to teaching science as a result of an intervention is now called for.

Based on the qualitative studies exploring the influence of an intervention on science teachers' pedagogical orientations, inquiry-based experiences can somehow facilitate inquiry-based orientations to teaching science. Faikhamta (2013) and Demirdögen and Uzuntiryaki-Kondakçi (2016) consistently found that facilitating informed understanding of the nature of science (NOS) and incorporating NOS as an instructional objective can promote inquiry-based orientations. Although these studies are inconsistent with Kind's (2016) study, showing mixed alignment between understanding of NOS and pedagogical orientations, Suh and Park (2017) showed that a change in views on students' learning as a result of the intervention focusing on argument-based inquiry can facilitate science teachers' adoption of more inquiry-based orientations. While which certain aspects of inquiry-based experiences positively influence science teachers' pedagogical orientations is an issue, professional development should nonetheless provide inquiry-based experiences for science teachers. Thus, the research questions guiding this study are as follows:

Research Questions

(1) Do science teachers improve their orientations to science teaching after engaging in an inquiry-based professional development?

(2) What are changes in reasons that science teachers provide when they adopt more inquiry-based orientations to teaching science?

Method

The current study is a mixed-methods research study in the sense that both quantitative and qualitative data are utilized to address the research questions. According to Creswell and Plano Clark (2011), the key advantage of mixed-methods research is that "the use of quantitative and qualitative approaches, in combination, provides a better understanding of research problems than either approach alone" (p. 5). While there are many ways in which quantitative and qualitative approaches can be combined, the current study employs an embedded design as one research stance is added to the other research stance. In doing so, the quantitative approach is utilized to determine whether or not an inquiry-based professional development does influence science teachers' orientations to teaching science, whereas the qualitative approach is employed concurrently to provide a more in-depth explanation of the quantitative results. In this regard, priority is given to the quantitative approach.

Context

The current study is conducted under the "Coupon for Teacher Development Project," which is a national collaborative project involving several Thai educational organizations, such as the Teacher Profession Development Institute (TPDI), the Office of the Basic Education Commission (OBEC), universities responsible for teacher education, and private sector institutions interested in providing teacher professional development. In this project, every government teacher, in any subject, is given a "coupon" by the OBEC to register according to their interests and needs for professional development programs that are developed and submitted by universities or the private sector. The submitted programs are evaluated, qualified, and approved by the TPDI, after which they are open for teachers to register for them. Among 84 approved programs, a program submitted by the University of Phayao called "Teaching and Learning Science Scientifically" is available for interested teachers who teach science at lower secondary levels (Grades 7–9).

Program

The program was conducted over two days during a weekend according to the OBEC's policy that programs should not take place during teachers' five working days. The program focuses on inquiry-based instruction where NOS is made explicit. It aims at modelling for teachers how scientific inquiry can be organized in a classroom setting in ways that some authentic aspects of science (for example, theory-laden NOS) can be highlighted. The program was launched in a role-playing format, where teachers assumed the roles of students working in groups and the authors acted as instructors. The program began with a brief activity to gain teachers' attention about theory-laden observations, as they were asked to observe Hanson's (1972) images and to interpret what those images represent. As different teachers interpreted these images differently and, in some cases, some teachers could not interpret what the images represent, the role of prior knowledge and beliefs guiding their perceptions and observations was discussed.

Once teachers became aware of their theory-laden observations, they were asked if this also happens when different scientists observe the same phenomenon. Some examples from the history of science were provided to illustrate that different observations can probably lead to generating different explanatory hypotheses, even with the same set of empirical evidence (for example, the cases of Darwin and Lamarck explaining evolution differently and Lavoisier and Priestley explaining combustion differently). In addition, the teachers were asked to discuss how a scientist comes up with an explanatory hypothesis of a phenomenon. This discussion was intended to introduce teachers to the idea of abductive reasoning as a process for generating an explanatory hypothesis (Kwon et al., 2006). A discussion then took place on the issue of how a scientist can empirically test an explanatory hypothesis. It was emphasized that, since an explanatory hypothesis often contains theoretical concepts, it cannot be tested directly, unless it is converted into a testable form of predictions (Kim et al., 2012).

Then teachers were introduced to inquiry-based instruction in the context of human fertilization. On a popular Thai web board, the following question was posted: "How do sperms know which direction to swim until they reach the egg?" This question was used in the program for various reasons. First, an understanding of the human reproductive system is one of the learning indicators in Thailand's science curriculum standards. Second, as scientific research in this area proceeds with different explanations (Eisenbach & Giojalas, 2006), teachers may not be certain about the issue, allowing them to engage in scientific practices in authentic ways. Teachers were asked to use their abductive reasoning to propose explanatory hypotheses about sperm guiding mechanisms. As a result, they collectively came up with three possible explanatory hypotheses, namely: (1) that chemical substances produced by the egg may attract the sperm, (2) that the sperm may "feel" the difference in temperature between the areas with and without the egg, and (3) that the sperm swim according to the flow of fluid in the woman's reproductive system.

Based on Chinn and Malhotra's (2002) framework for epistemologically authentic inquiry, the teachers were asked to engage in a task called "verbal design of studies," which encouraged them to formulate one of the three proposed explanatory hypotheses as a testable question and to verbally design a scientific experiment to address that question. Once teachers came up with their design of scientific experiments, the teachers and instructors engaged in a discussion to evaluate and improve the validity of the designed experiments. Then the teachers were presented with evidence from scientific studies (e.g., Eisenbach, 1999; Eisenbach & Giojalas, 2006; Eisenbach & Tur-Kaspa, 1999) in order for them to engage in a task called "Evidence Evaluation" to encourage them to use available evidence to make inferences to arrive at the best explanation. It is important to note that, although the proposed three explanatory hypotheses are different, they do not contradict each other. Thus, a combination of these explanatory hypotheses is possible for the teachers to build a complex explanation.

Some NOS aspects were explicitly discussed during and after the inquiry-based activities (Abd-El-Khalick & Lederman, 2000). After proposing the three explanatory hypotheses, for example, there was a discussion about why different teachers proposed different explanatory hypotheses. They were reminded that different interpretations of Hanson's (1972) images are possible; this discussion aimed to enhance the teachers' views of theory-laden NOS in a contextualized way. Moreover, the teachers also discussed how they used imagination and creativity to propose explanatory hypotheses, as well as to design the experiments. In this way, the so-called scientific method was challenged, as different teachers interested in the same explanatory hypothesis designed different experiments. Furthermore, there was a discussion on how and why different teachers made different inferences based on the same evidence. Despite the different inferences, the teachers were explicitly informed that their explanations must be based on available evidence. Once teachers reached an evidence-based explanation, they also discussed whether and how it could be changed.

Participants

Sixty-seven teachers (51% female, 38% male, and 11% of unidentified gender) voluntarily participated in the current study based on opportunistic sampling (Patton, 1990), as they had registered to engage in the professional development program. They were diverse in age, with 23% being 21–30 years old, 38% being 31–40 years old, 25% being 41–50 years old, and 14% being 51–60 years old. All of the teachers had a bachelor's degree, while 51% also had a master's degree. Their educational backgrounds were diverse, with 29% having studied general science, 22% chemistry, 22% biology, 17% physics, and 11% astronomy. The diversity in their educational backgrounds is understandable, given the fact that Thai teachers sometimes have to teach science outside their content specialties (Siribanpitak, 2019). They were also diverse in terms of teaching experience, which included 0–5 years (32%), 6–5 years (47%), and even more than 15 years (20%). About 80% of the teachers taught science at lower secondary levels, while the rest taught science at higher secondary levels.

Instruments

While there are many ways to assess science teachers' orientations to teaching science, the current study employs the instrument called the Pedagogy of Science Teaching Tests (POSTT) developed by Cobern et al. (2014). This instrument is chosen for the following reasons. First, it is designed to assess and classify science teachers' orientations to teaching science in a way that aligns with Thailand's science education reforms that have resulted in a focus on inquiry-based instruction. Second, its structure is consistent with the science discipline classification according to Thailand's national core science curriculum standards. Third, it is a contextualized assessment in that questions based on instructional scenarios allow science teachers to make deliberate decisions and to provide their underlying pedagogical reasons within a certain period of time. Fourth, its four-choice format allows for statistical comparison. Fifth, it has been translated into several languages, and has been widely used in many countries (e.g., Guven et al., 2019).

There are four versions of the POSTT, namely POSTT-1, POSTT-2, POSTT-3, and POSTT-4 (Mallinson Institute for Science Education, 2022). Each version consists of 16 items, with a variety of science topics and instructional situations. In the current study, two versions were randomly selected (POSTT-4 for the pre-test and POSTT-1 for the post-test) before they were translated to Thai and examined by the researchers to ensure validity. The reliability values of the pre-test and the post-test as calculated using Cronbach's alpha were 0.64 and 0.62, respectively. These values are slightly lower than 0.70, given that the items of POSTT are contextualized (Cobern et al., 2014). The pre-test and the post-test have four items in common, which can be used for the purpose of statistically comparing science teachers' orientations to teaching science before and after engaging in the inquiry-based activities of the program. As illustrated in Figure 1, each item of the POSTT asks science teachers to choose one of the four options representing different kinds of orientations to teaching science: didactic direct, active direct, guided inquiry, and open inquiry. Table 1 describes the key characteristics of each orientation to teaching science, reflecting the different modes of the fundamental epistemologies of science, that is, ready-made science versus science-in-the-making.

Figure 1

An Example of an Item in the POSTT

Mr. Goodchild is doing a frog dissection with his 10th graders to help teach anatomy. Thinking about how you would teach a lesson, which of the following is most similar to what you believe is the best way to incorporate a dissection into a lesson?

A. It should be used as a stand-alone step-by-step activity for students to explore the frog's anatomy and raise discussion questions on their own. [Open inquiry]
B. It should be used as a follow-up step-by-step student activity after Mr. Goodchild explains exactly what students will need to notice about the frog anatomy. [Active direct]
C. It should be used as a step-by-step student activity while answering probing questions, followed up by teacher-led discussion and clarifications. [Guided inquiry]
D. It should be used as a step-by-step demonstration by Mr. Goodchild while he explicitly points out what students need to know about frog anatomy. [Didactic direct]

Note. (Cobern et al., 2014, p. 2281)

Table 1

Descriptions of orientations to teaching science reflected in the POSTT

Fundamental epistemic mode	Variant for each mode	Descriptions
Ready-made science	Didactic direct	Teacher presents and explains science content directly. Teacher illustrates with example or demonstration. No student activities.
	Active direct	Teacher presents and explains science content directly. Students actively engage in verification or confirmation.
Science-in-the-making	Guided inquiry	Students actively explore phenomenon or idea with teacher guidance toward desired science content.
	Open inquiry	Students actively explore phenomenon or idea as they choose. Teacher facilitates process but does not prescribe.

Note. (Cobern et al., 2014, p. 2270)

Data Collection

At the beginning of the first day of the program, the pre-test POSTT-4 was distributed to all 67 participating teachers. The teachers were encouraged to choose one option that best fits their pedagogical preferences and to write detailed reasons for their choice. They were also informed that there were no right or wrong answers, because the pre-test aims at assessing their preferences rather than their knowledge. Most of the teachers took about one and a half hours to complete the pre-test. Then the teachers engaged in the inquiry-based activities about human fertilization, as previously described. At the end of the second day of the program, the post-test POSTT-1 was distributed to all the participating teachers using the same process of administration. Only 65 teachers returned the post-test, as two had left. Most of the teachers took about one hour to complete the post-test. It is important to note that the teachers were asked not to write their names or any other identification on either the pre-test or the post-test, in order to ensure free expression of the reasons for their chosen orientations to teaching science. Given the short timeframe of this study, different versions of the POSTT were used to reduce the influence of retesting as a threat to its internal validity (Yu, 2021).

Data Analysis

According to Cobern et al. (2014), the answers chosen in the POSTT can be quantified using a scoring system in which one point is given for each answer representing a didactic direct orientation, two points are given for an active direct orientation, three points for a guided inquiry orientation, and four points for an open inquiry orientation. The increase in points indicates a pedagogical tendency toward scientific inquiry. This scoring system allows for calculating individual science teachers' scores for each common item, average scores for four common items, and average scores for all 16 items in the pre-test and the post-test. These individual and average scores can then be compared using relevant statistical methods. Shapiro-Wilk tests were performed to test the normality of the data sets. It appears that all data sets are not normally distributed ($p < .05$). Thus, Mann-Whitney U tests were performed for the sets of unpaired data between the pre-test and the post-test, to determine whether the inquiry-based activities influenced orientations to teaching science.

Using quantitative data analysis, the reasons provided by the science teachers in the pre-test and the post-test were qualitatively analyzed using content analysis. In doing so, Friedrichsen et al.'s (2011) framework was used as an initial coding system that focuses on the three dimensions of orientations to teaching science, namely: (1) goals and purposes of science teaching, (2) views of science, and (3) beliefs about science teaching and learning. However, as Harris and Rooks (2010) have pointed out, science teachers might be concerned about other aspects when deciding to adopt inquiry-based instruction, such as students, materials, tasks, scientific ideas, and the classroom community. During the qualitative data analysis, it is necessary to keep the coding system open for these other aspects which may concern science teachers. Thus, an iterate process of data analysis was used, as new categories of factors influencing orientations to teaching science emerged during the coding process (see Figure 5 and Figure 6). The tentative results were then discussed among the researchers to solve any discrepancies until a consensus was reached.

Results

As a mixed-methods research, quantitative and qualitative data are used in combination in the current study to understand whether and in what respects the inquiry-based professional development influences science teachers' orientations to teaching science. Therefore, in this section, the quantitative results are presented first to answer the first issue. Then, the qualitative results are presented to address the second issue and explain the quantitative results.

Improvement in Orientations to Teaching Science

By assuming that the pre-test and the post-test are equivalent with respect to their reliability in assessing orientations to teaching science, the average scores from all 16 items of both tests were compared. As presented in Table 2, it appears that the average score for the post-test is higher than the average score for the pre-test, which is significantly different at the level of 0.05 ($U = 1335.500$, $p = .000$, effect size = 0.388). This result suggests that science teachers may improve their orientations to teaching science by engaging in inquiry-based professional development. However, it could be argued that the improvement partly results from differences between the two tests, which have only four items in common. Thus, in order to validate this result, the average scores for the four shared items in the two tests were compared. As demonstrated in Table 2, it appears that the average score for the post-test is significantly higher than the average score for the pre-test, at the level of 0.05 ($U = 1325.500$, $p = .000$, effect size = 0.391). This result confirms that the program influences science teachers to adopt more inquiry-based orientations to teaching science.

Table 2

Descriptive Data of the Average Scores in Both Tests

Items	Tests	N	Min	Max	Mean	SD
All sixteen items	Pre-test	67	2.19	3.75	3.03	0.33
	Post-test	65	2.25	3.75	3.25	0.32
Four shared items	Pre-test	67	2.00	4.00	2.99	0.42
	Post-test	65	2.25	4.00	3.28	0.44

To better understand the improvement in science teachers' orientations to teaching science, the scores from each of the four shared items in the pre-test and the post-test were also compared. According to descriptive data presented in Table 3, scores in three items (i.e., frog dissection, rain and water flow, and light reflection) in the post-test are higher than those in the pre-test, while the post-test score in the item on force and motion is slightly lower when compared to that in the pre-test. However, the Mann-Whitney U tests reveal that only the score in the item on frog dissection in the post-test is significantly higher than that in the pre-test, at the level of 0.05 (U = 974.500, p = .000, effect size = 0.552). The differences in the other three items are not significant. This result suggests that, while the inquiry-based professional development did influence the science teachers' orientations to teaching science, this influence may not equally be present in all instructional scenarios. Hence, more detailed analysis is required to reveal a tendency of significant changes in science teachers' orientations in the item on frog dissection.

Table 3

Descriptive Data of the Scores in Each Shared Item in Both Tests

Items	Tests	N	Min	Max	Mean	SD
Frog dissection	Pre-test	67	1	4	2.60	0.89
	Post-test	65	1	4	3.54	0.79
Force and motion	Pre-test	67	2	4	3.58	0.65
	Post-test	65	1	4	3.52	0.73
Rain and water flow	Pre-test	67	1	4	2.97	0.63
	Post-test	65	1	4	3.11	0.64
Light reflection	Pre-test	67	1	4	2.81	0.72
	Post-test	65	1	4	2.94	0.88

As the science teachers had significantly improved their orientations to teaching science only in the item on frog dissection, it is necessary to understand what makes them adopt more inquiry-based orientations in this item after engaging in the inquiry-based professional development. The percentages of science teachers who chose each option of orientations to teaching science were calculated to reveal a tendency in this improvement. As illustrated in Figure 2, it appears that a substantial number of the science teachers changed from choosing less inquiry-based orientations to teaching science—that is, didactic direct (1), active direct (2), or guide inquiry (3) in the pre-test—to choosing the open-inquiry orientation (4) in the post-test. When compared to what happened in the other items such as rain and water flow and light reflection, a smaller number of the science teachers made a similar change, as illustrated in Figure 3 and Figure 4 respectively. Thus, the science teachers' reasons, written in the item on frog dissection in the pre-test and the post-test, were focused and compared.

Figure 2

Percentages of Each Orientation in the Item on Frog Dissection

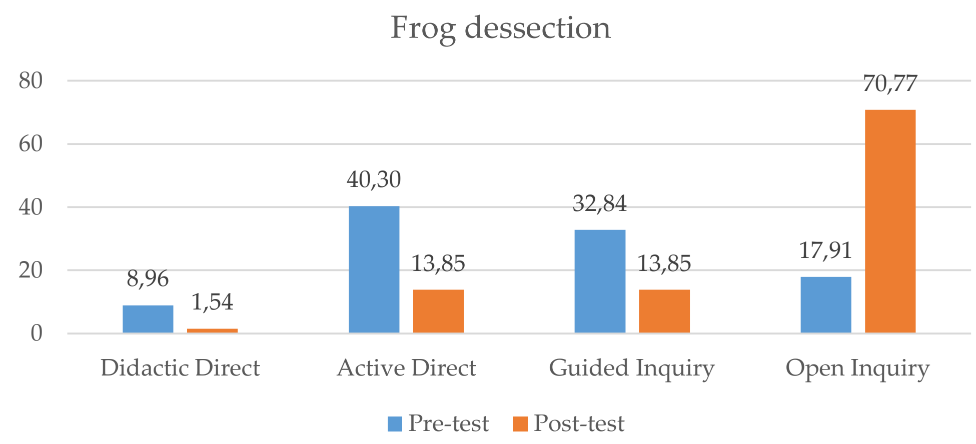


Figure 3

Percentages of Each Orientation in the Item on Rain and Water Flow

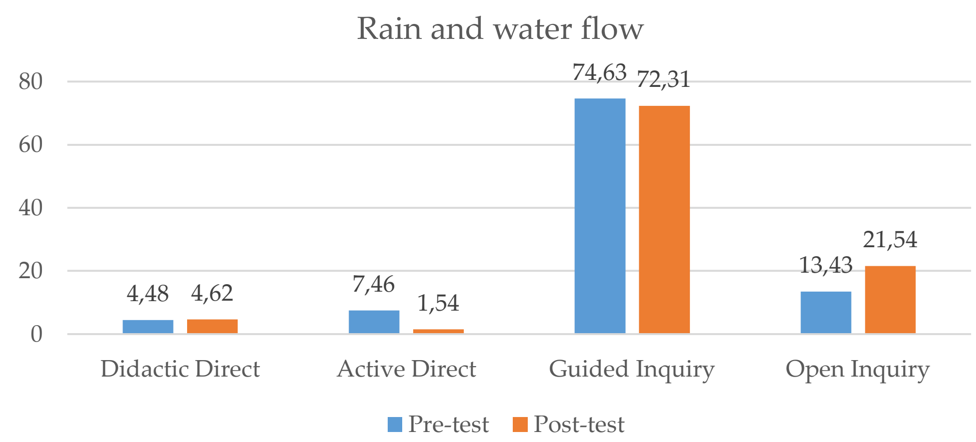
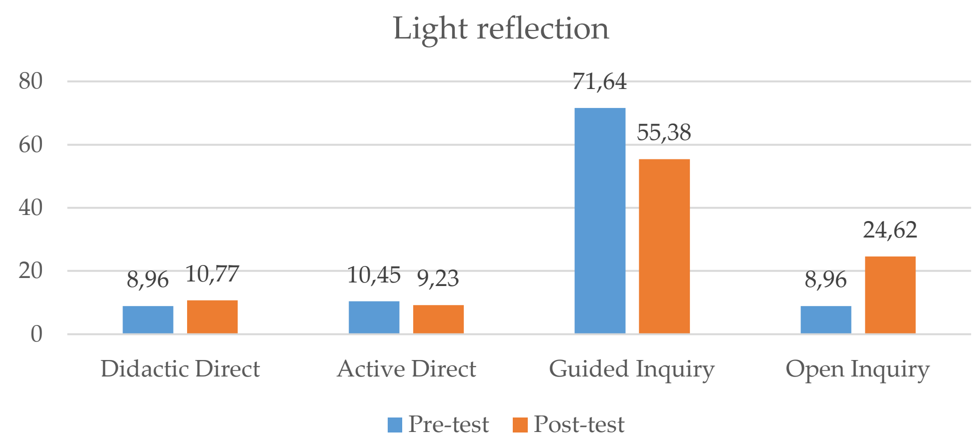


Figure 4

Percentages of Each Orientation in the Item on Light Reflection



Changing Reasons for More Inquiry-based Instruction

Using Friedrichsen et al.'s (2011) three-dimensional framework for orientations to teaching science (i.e., the goals and purposes of science teaching, views of science, and beliefs about teaching and learning) as an initial coding system, three codes could be assigned to science teachers' reasons for choosing particular orientations to teaching science. These codes include: (1) instructional objectives, (2) NOS, and (3) students' ways of learning as related to the three dimensions of orientations to teaching science respectively. However, it is clear that these codes are not sufficient for a full analysis of science teachers' reasons, as they also concerned and explicitly mentioned other factors (Harris & Rooks, 2010) for choosing particular orientations to teaching science. While keeping the initial coding system open, two more codes relevant to additional emerging reasons were added, namely: (4) students' readiness and safety and (5) learning materials. Given these five codes, it is more likely to capture science teachers' orientations to teaching science.

As illustrated in Figure 5, in the pre-test science teachers tended to mention students' readiness and safety more often when choosing the didactic-direct orientation (1) than when choosing the other orientations. For example, a science teacher preferring the didactic-direct orientation reasoned: "It's an experiment involving instruments that students may not be familiar with. The teacher must demonstrate for safety" (T12). In addition to students' readiness and safety, some science teachers were concerned about learning materials (i.e., the frog) being damaged by students. For example, a science teacher preferring the active-direct orientation reasoned: "Frog's internal organs may be teared and mushy" (T11). Moreover, despite a preference for hands-on activities, some science teachers were concerned that they would not be able to achieve the learning objective by allowing the students to do an open inquiry. For example, a science teacher preferring the active-direct orientation argued: "Frog dissection is deliberately complex. Without providing steps, students won't get content knowledge" (T40).

Figure 5

Percentages of Coded Reasons for Each Orientation in the Pre-Test

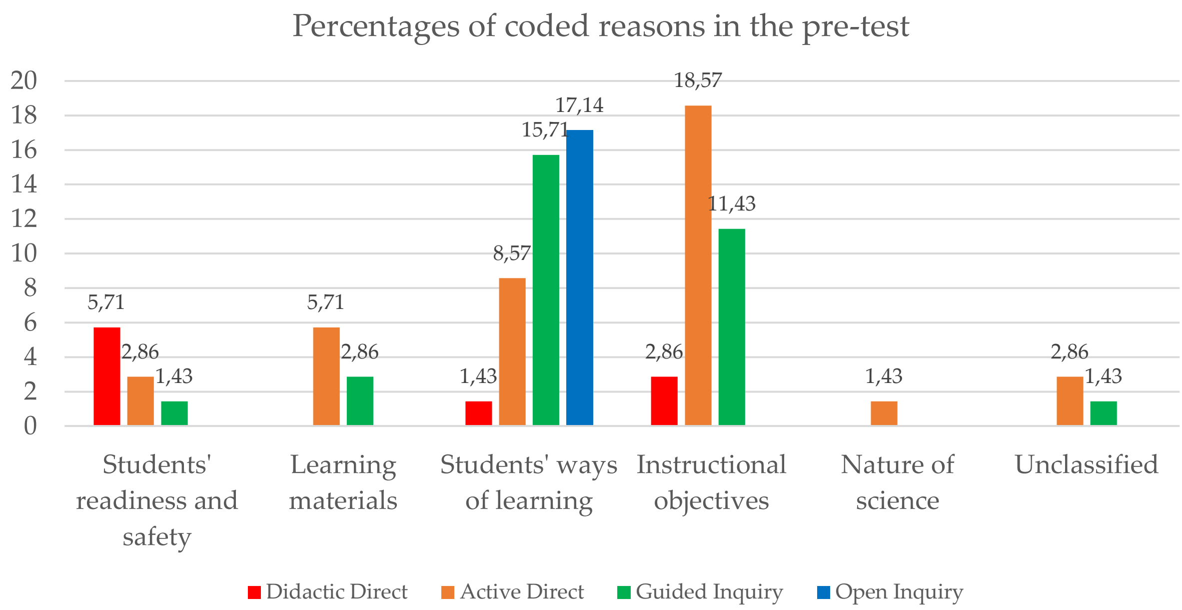
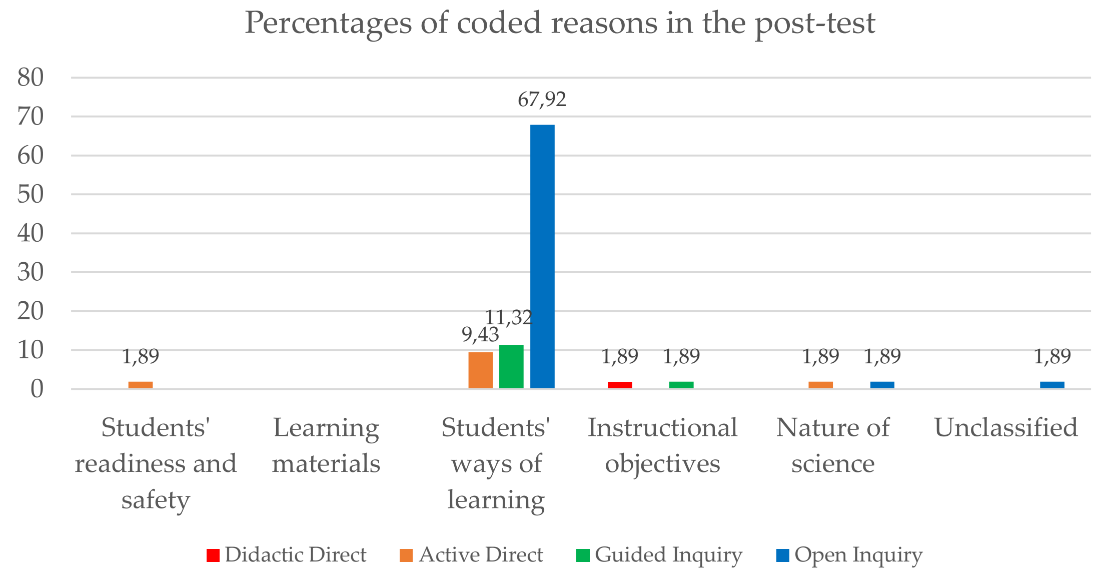


Figure 6

Percentages of Coded Reasons for Each Orientation in the Post-Test



While science teachers with a preference for the didactic-direct orientation or even the active-direct orientation are not very concerned about students' ways of learning, those who chose more inquiry-based orientations (i.e., guided inquiry and open inquiry) focused mainly on this aspect. For example, a science teacher choosing the open-inquiry orientation reasoned: "Because students are at higher secondary levels, the teacher should let them study and learn by asking questions to find answers by themselves, and then bring data into a discussion with others" (T41). In a similar vein, a science teacher with a preference for the guided-inquiry orientation reasoned: "Learning by doing. [Students] learn from a hands-on activity. Practice it. They get to analyze, discuss, and answer questions in worksheets. This is good for them" (T7). Regardless of the kinds of orientations chosen, it is important to note that science teachers rarely mentioned NOS. Only one of them, who chose the active-direct orientation, reasoned: "It's steps close to scientific experiments" (T19).

After engaging in the inquiry-based professional development, science teachers tended to focus more on students' ways of learning than other factors. As illustrated in Figure 6, it is apparent in the post-test that most of their reasons refer to how students would best learn in the inquiry-based instruction, with emphasis on students' thinking, individual differences, and classroom discussion. For example, a science teacher choosing the open-inquiry orientation reasoned: "The teacher should let students do according to their thinking first, and then ask questions for discussions for learning together" (T7). In a similar vein, a science teacher with an orientation to open inquiry reasoned: "Because letting students dissect the frog freely will lead them to thinking differently [from what they initially thought]. And this will help construct a new knowledge for them" (T20). Moreover, a science teacher preferring the open-inquiry orientation reasoned: "Because students have individual differences. Thus, doing and discussing together in a classroom will lead to various kinds of knowledge with long retention" (T2).

Focusing more on students' ways of learning does not mean that science teachers are less concerned about the instructional objectives of the lesson. Instead, as the above excerpts demonstrate, they seem better able to achieve a compromise between the instructional objectives and students' ways of learning. In other words, while being aware of what to achieve instructionally (i.e., to study the frog anatomy), science teachers also know how to achieve the instructional objectives in a manner that better aligns with students' ways of learning—that is, keeping the lesson open for students' initial thinking before facilitating their acquisition of scientific thinking and knowledge, using questions and discussions. In doing so, some science teachers argue that, in addition to the given instructional objectives, students can learn other important things as well. For example, a science teacher with the open-inquiry orientation reasoned: "In allowing students to freely ask questions and to discuss the answers, this way will produce various kinds of knowledge and concepts" (T29). Nonetheless, similar to what happened in the pre-test, NOS was rarely mentioned.

Discussion

As research has been conducted to investigate science teachers' PCK (Abell, 2008), which includes their orientations to teaching science (Friedrichsen et al., 2011), it is well documented that experiences in scientific inquiry can facilitate inquiry-based orientations to teaching science (Avraamidou, 2013). However, such a conclusion often comes from studies investigating preservice science teachers' historical learning experiences (e.g., Eick & Reed, 2002), rather than those investigating science teachers experiencing scientific inquiry in the context of professional development or teacher education. Thus, while the current study confirms this conclusion, it also provides evidence that inquiry-based professional development does influence science teachers to adopt more inquiry-based orientations to teaching science. Moreover, it also provides an insight that such a positive influence occurs especially when science teachers focus on how students learn about science and know how to achieve instructional purposes in a manner that aligns with students' ways of learning.

The current study's results support previous findings in the literature that understandings about students can be a source of science teachers' orientations to teaching science in some respects (Friedrichsen & Dana, 2005). For example, Ramnarain and Schuster (2014) have noted that science teachers' perceptions of students' abilities can be a factor that influences their orientations to teaching science. Thus, training science teachers to recognize and understand students' characteristics and backgrounds (e.g., socio-cultural practices, experiences, and beliefs) can positively influence their orientations to teaching science (Mavuru & Ramnarain, 2018). Moreover, in their professional development focusing on argument-based inquiry, Suh and Park (2017) have found a strong connection between science teachers' orientations to teaching science and their knowledge of student understanding. In addition to these findings, the current study contributes that science teachers' focus on students' ways of learning can influence science teachers' orientations to teaching science toward inquiry (Ladachart, 2020).

Although the current study involves science teachers engaging in inquiry-based professional development with explicit emphasis on NOS, it is apparent in the reasons they gave in both tests that NOS is rarely mentioned as a factor influencing their orientations to teaching science. This is opposed to what Friedrichsen et al. (2011) have theoretically proposed, namely that orientations to teaching science have beliefs about science as one dimension. However, the current study's results support Kind's (2016) finding with preservice science teachers that connections between orientations to teaching science and beliefs about science are mixed, and thus it is "inconclusive about beliefs about science as a component" of orientations to teaching science (p. 147). As a result, it is suggested that NOS should be considered as subject matter to be taught (Faikhamta, 2013), rather than a component of orientations to teaching science. This consideration can explain why science teachers' beliefs about science do not directly interact with their PCK (Demirdogen, 2016).

The current study's results accordingly do not support previous studies demonstrating that facilitating informed understanding of NOS and incorporating NOS as an instructional objective can promote science teachers' inquiry-based orientations to teaching science (Demirdögen & Uzuntiryaki-Kondakçi, 2016; Faikhamta, 2013). Based on these previous studies, there are conditions that NOS-focused interventions can positively promote inquiry-based orientations—that is, (1) science teachers developing informed understanding of NOS and (2) science teachers endorsing NOS as an instructional objective. It is important to note that, in the current study, while science teachers are exposed to NOS explicitly, it is not certain that they improve their understanding of NOS. Nor is it certain that they endorse NOS as an instructional objective. Rather than promoting informed understanding of NOS and ways to promote it instructionally in classrooms, inquiry-based professional development provides opportunities for science teachers to experience and perceive a new way by which students can learn science. It is possible that this aspect influences science teachers to adopt more inquiry-based orientations (Suh & Park, 2017).

Based the results of the current study and in light of Friedrichsen et al.'s (2011) framework of orientations to teaching science, two dimensions of orientations to teaching science can be confirmed. These two dimensions are: (1) the goals and purposes of science teaching and (2) beliefs about teaching and learning. In respect of the first dimension, it is apparent that science teachers consider the instructional objectives to guide decisions in choosing instructional strategies. In other words, science teachers tend to use instructional strategies in a way that is congruent with their orientations to teaching science (Brown et al., 2013). In respect of the second dimension, it is evident that, when focusing more on students' ways of learning, science teachers are more likely to choose inquiry-based instruction. In other words, they make decisions about instruction based on their views on students' learning (Suh & Park, 2017). Another proposed dimension (i.e., beliefs about science) does not play a role in guiding instructional strategies. Thus, it should not be regarded as a component of orientations to teaching science (Kind, 2016).

The literature regarding teacher professional development indicates that a one-shot workshop is normally ineffective in changing teachers' instructional practice (Goldenberg & Gallimore, 1991). Moreover, given that science teachers' orientations to teaching science are often resistant to change (Brown et al., 2013), it is less likely that two-day professional development as implemented in the current study can significantly develop more inquiry-based orientations to teaching science. While researchers expect science teachers to dramatically change their teaching practice from lecture-based approaches to inquiry-based ones as a result of workshop. Rather, as the current study demonstrates, a short-term professional development experience can enable science teachers to perceive a new way by which students can learn science via inquiry and thereby a new way by which they can teach science at least in some instructional situations. Taking this as a starting point of a long departure, much subsequent effort is then required to help science teachers to pursue a change toward inquiry-based instruction (Crawford, 2007).

Implications

Given the fact that science teachers' orientations to teaching science are often resistant to change (Brown et al., 2013), the current study provides some implications for science teacher education and professional development. First, it can be suggested that inquiry-based experiences can facilitate science teachers adopting more inquiry-based orientations to teaching science. Second, for those inquiry-based experiences to be effective, it is important that science teachers are encouraged to focus on how students can learn science in meaningful ways, not just by seeing and listening to a demonstration or lecture by the teacher. This implication is congruent with what Schneider and Plasman (2011) suggested in their review of the literature on the learning progression of science teachers' PCK, that "teacher thinking appears to progress first to thinking about learners" (p. 555). Once achieved, inquiry-based orientations to teaching science can be a powerful support for developing science teachers' PCK (Brown et al., 2013).

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