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The Development of In-Service Science Teachers' Understandings of and Orientations to Teaching the Nature of Science within a PCK-Based NOS Course

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Abstract The nature of science (NOS) has become a central goal of science education in many countries. This study sought an understanding of the extent to which a nature of science course (NOSC), designed according to the conceptualization of pedagogical content knowledge (PCK) for teaching nature of science (NOS), affects in-service science teachers' understanding and learning of NOS, and their orientations towards teaching it. A qualitative research approach was employed as a research methodology, drawing upon pre- and post-instruction NOS questionnaires, field notes, and in-service teachers' weekly journal entries and assignments. Open-ended NOS questionnaires, used to assess participants' understandings of NOS, were analysed and categorized as either informed, partially informed and naive. Other qualitative data were analysed through an inductive process to identify ways in-service teachers engaged and learned in the NOSC. The results indicate that at the beginning of the course, a majority of the in-service science teachers held naive understandings of NOS, particularly with respect to the definition of science, scientific inquiry, and differences between laws and theories. They viewed implicit project-based science and science process skills as goals of NOS instruction. By engaging in the course, the in-service science teachers developed an understanding of NOS and orientations to teaching NOS based on various elements, especially reflective and explicit instruction, role modelling, and content- and non-content embedded instruction. The aim of this study is to help science teacher educators, consider how to support and develop science teachers' understandings of NOS while being mindful of PCK for NOS, and develop methods for teaching NOS frameworks.

Keywords Nature of science · Science teacher · Pedagogical content knowledge (PCK) · Orientations to teaching nature of science · PCK for teaching the nature of science

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Introduction

Student understandings of the nature of science (NOS) have been a central goal of science education programs in many countries (Lederman 1992; McComas and Olson 1998). The nature of science is an important element of scientific literacy that students should be encouraged to develop through their schooling. An understanding of NOS can function as a powerful means of developing various aspects of science students' education, and can help students to better understand scientific content, as well as maintain a positive attitude towards science and scientific attitudes (McComas et al. 1998). To help students reach an understanding of NOS, educators have an important role in providing them with learning opportunities. Unfortunately, many studies consistently show that science teachers possess inadequate conceptions of NOS (Haidar 1999; Lederman 1992). Further, science teachers seem to believe that science is an application of technology (Yalvac et al. 2007), scientific knowledge is objective and absolute (Akerson and Donnelly 2008), scientific methods are the only way to gain knowledge (Abd-El-Khalick and BouJaoude 1997; Lederman 1992), science is a step-by-step process, scientific theories are laws that govern the behaviour of scientific phenomena (Haidar 1999; Lederman 1992), and finally that science, technology and society are independent (Yalvac et al. 2007). Finally, science teachers seldom integrate aspects of NOS or make it explicit to students in science learning activities (Mellado et al. 2007).

A growing effort to help science teachers develop their understanding of NOS and related teaching practices has been an ongoing challenge in science teacher education. A great deal of research has indicated that science teachers should be provided with opportunities to develop not only their understanding of NOS, but also their ability to transform this understanding to facilitate student interpretation in the classroom context (Abell 2008; Akerson et al. 2006; Haefner and Zembal-Saul 2004; Haunscin et al. 2011); this is referred to as PCK for teaching NOS. The PCK for teaching NOS is needed to enable teachers to address NOS in their teaching practice (Abd-El-Khalick and Lederman 2000). The notion behind this view is that familiarity with either general pedagogies or an understanding of the subject alone is not enough for teaching NOS. Rather, pedagogy must be blended with content, such as NOS. Since PCK has been described as the hallmark of good teaching practice in the disciplines (Berry et al. 2008; Corrigan et al. 2010) and represents an important concept in defining the characteristics of good teaching (Magnusson et al. 1999), it is appropriate to think of it in the context of teaching NOS. It is reflected in teachers' understanding of which concepts of NOS are to be taught, the selection of appropriate instructional materials, and the use of pedagogical tools such as metaphor and analogy to help students interpret NOS (Haunscin et al. 2011). Unfortunately, there is an absence of studies on developing science teachers' understanding of NOS and strategies for teaching it within a PCK framework.

The purpose of this study was to employ the PCK as a framework for developing Thai science teachers' understandings of NOS, and their orientations towards teaching it. As is the case in other countries, science teachers in Thailand are currently undergoing a period of reform in which they are expected to understand NOS, and be able to present their understandings to students in an accessible way (The Institute of Promotion of Science and Technology Teaching (IPST) 2002). As a teacher educator, the author intended to develop science teachers' understandings of NOS and therefore develop his own strategies for teaching it. This empirical study is presented as an example of research on developing science teachers' understanding of NOS and argues that this type of study may significantly add to the value of the concepts of both PCK and NOS within the domain of research on science teacher education. The specific research questions were:

1. What is the impact of a PCK-based NOS course on in-service teachers' understanding of NOS, and orientation towards teaching NOS?
2. In which ways do in-service science teachers develop their understanding of NOS and orientations to teaching NOS in the context of the PCK-based NOS course?

Theoretical Underpinnings of This Study

Nature of Science

The term "nature of science" (NOS) has been defined by several science educators. Like scientific knowledge, conceptions of the nature of science are tentative and dynamic (Lederman 2002). They have changed throughout the development of science and as a result of systematic thinking by various researchers about its nature and functioning. McComas et al. (1998) argue that NOS is the combination of various social studies of science including the history, sociology, and philosophy of science, and also research from the cognitive sciences that provides a rich description of what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavours (p. 4). Lederman (1992) argues that NOS refers to the epistemology and sociology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development. There is a consensus with respect to certain specific aspects chosen for study in research reports on teachers' views on NOS. These aspects are: definition of science (Yalvac et al. 2007); characteristics of scientific knowledge (Haidar 1999; Lederman 1992); characteristics of scientists (Haidar 1999; Lin and Chen 2002); and interaction of science, technology, and society (Yalvac et al. 2007). Succinctly, the American Association for the Advancement of Science (AAAS) (1993) suggests, the nature of science can be divided into three main aspects: scientific world view, scientific inquiry, and scientific enterprise.

In the first aspect, the world is viewed as an understandable entity within which science attempts to describe, explain, and predict natural phenomena. Science cannot provide answers to all questions, since scientific knowledge, while durable, has a tentative character, and scientific knowledge relies heavily, but not entirely, on observation. In the second aspect, science demands evidence and is a blend of logic and imagination. Also experimental evidence requires rational arguments and skepticism. Scientists are creative, and scientists require accurate record keeping, peer review and replicability. Finally, in the third aspect, science is viewed as a series of complex social activities, science and technology impact each other, and scientific ideas are affected by their social and historical context.

PCK for Teaching NOS

PCK has become a central focus for the study of how to teach particular content to particular students at a particular point in time (Abell 2008; Berry et al. 2008; Nilsson and Loughran 2011). PCK was first proposed by Shulman (1986), and his work forms the knowledge base for research on PCK. In his view, PCK is characterized as content knowledge that is related to its "teachability". It includes "the way of representing and formulating the subject that make it comprehensible to others" and "an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons" (Shulman 1986, p. 9). Most researchers have embraced Shulman's ideas but have broadened and further studied different conceptualizations of PCK (e.g., Berry et al. 2008; Grossman 1989; Magnusson et al. 1999; Park and Oliver 2008). Bucat (2004) suggests that chemistry teachers should know 'how to teach stoichiometry', or 'how to teach chemical equilibrium', or 'how to teach stereochemistry'. The rationale behind knowing how to teach a particular topic is that, for example, the demands of teaching and learning about stoichiometry are different from the demands of teaching and learning about stereochemistry. Similarly, if one views NOS as content and target aspects of NOS as topics to be taught, it is important to be familiar with content-specific knowledge relevant to NOS aspects. If one wishes to teach, for example 'NOS aspect of laws and theories' to specific groups of students in a particular context, the demands of teaching and learning this aspect may be different from the demands of teaching about the 'NOS aspect of tentativeness'.

NOS is considered to be subject-specific content that has its own concepts, technical terms and topics. The teaching and learning of NOS are unique and inherent to these attributes. Nature of science is regarded as difficult content for students, and teaching NOS is a challenging task for science teachers (Abd-El-Khalick and Lederman 2000). Science teachers are required to not only understand NOS, but must also know how to teach NOS to a particular group of students. Even though PCK for NOS has been discussed for decades, research on PCK for NOS is seldom reported in the literature. Haunscin et al. (2011) have notably proposed a model of PCK for NOS modified from a framework developed by Magnusson et al. (1999). The PCK for teaching NOS consists of a teacher's orientation towards science, and their knowledge of curriculum, learners, instructional strategies and assessment. These components reflects the following important factors for science teachers: how they view NOS, how they understand the position of NOS in curriculum standards and materials, the establishment of NOS among student learning outcomes, general understanding of students' conceptions and difficulties related to NOS, the creation of teaching strategies and materials, and assessment of students' learning about NOS. Among these components of PCK for NOS, teachers' orientation to teaching NOS forms the basis of other PCK elements. It can be viewed as a conceptual map used to develop and enact specific teaching and learning activities, as well as a referent that organizes their knowledge (Tobin et al. 1994). In other words, orientations to teaching NOS influence instructional decisions about class goals and objectives, curriculum materials, activities and assignments for students, and evaluation of student learning.

Methods to Develop Teachers' Understanding of NOS, and Their PCK for NOS

The context for developing teachers' understanding of NOS and learning how to teach specific content such as NOS is an important consideration in the context of science teacher education. Researchers and educators have investigated what contexts encourage teachers to develop their understanding of NOS. Much of this research consistently suggests that teaching NOS through an explicit approach is more effective in engaging teachers to gain greater understanding about NOS than an implicit approach (Akerson et al. 2000; McComas et al. 1998; Schwartz et al. 2004). The reflective and explicit approach for teaching NOS is the method by which teacher educators provide science teachers with inquiry-based or hands-on activities that resonate with their views about NOS. Instead of engaging only with activities related to the scientific method or inquiry, science teachers are provided with explicit discussion about the various aspects of NOS. Abd-El-Khalick and Lederman (2000) argue that the basic difference between implicit and explicit approaches lies in the extent to which learners are provided with opportunities to reflect on key aspects of NOS. In the implicit approach, NOS is viewed as a by-product of students' engagement in inquiry-based activities. As a result, there are no direct references to NOS. On the other hand, an explicit approach encourages science teachers to design a plan and establish NOS as a goal of science learning in the classroom. Additionally, some research has indicated that a historical approach can enhance science teachers' understanding of NOS (Lin and Chen 2002). The historic approach employs episodes from the history of science to illustrate various aspects of NOS. It can enhance teachers' understanding of the nature of creativity, the theory-based nature of scientific observations, and the functions of theories (Lin and Chen 2002). Abd-El-Khalick and Lederman (2000) have suggested that PCK for NOS may be enhanced by encouraging teachers to address NOS intentionally in their classrooms, and by using history of science (HOS) as a source for the examples, analogies, metaphors, and stories related to the aspects of NOS.

Reflective and explicit teaching strategies embedded in various contexts help science teachers retain both their understanding of NOS and an awareness of these contents (Abd-El-Khalick and Akerson 2009; Akerson et al. 2006). Since these strategies are based on metacognitive approaches, science teachers have the opportunity to discuss and deeply reflect on the various aspects of NOS. While being mindful of the PCK required for teaching NOS, Abd-El-Khalick and Lederman (2000) have suggested that, based on PCK for teaching NOS, science teachers should have opportunities to design lesson plans on NOS in a microteaching course, design instructional units on NOS in a science curriculum course, and design alternative methods to assess students' understanding of NOS. These ideas will help teachers consider the various dimensions related to NOS and the teaching of NOS in specific contexts. In addition, alerting science teachers of their alternative conceptions of NOS before engaging in NOS instruction may facilitate modifying their ideas and adopting more current conceptions (Akerson et al. 2000).

Methodology

In this study, a qualitative research approach based on an interpretive paradigm (Patton 2002) was used to build an understanding of how in-service teachers developed their understandings of NOS and orientations to teaching NOS. The author views educational environments such as classrooms and schools as complex systems. A qualitative research approach is thus believed to provide appropriate direction in order to generate answers to the research questions.

Participants

Participants in this study were 25 Master of Education in Science Education (M.Ed. in Science Education) students, enrolled in the Nature of Science Course in the first semester of 2010 (June to September). All participants were in-service science teachers who had 1 to 10 years of teaching experience in primary or secondary schools. Of these teachers, 20 had obtained B.Ed. (Science Teaching), and five had B.Sc. degrees majoring in chemistry, biology or physics with a graduate diploma in teaching science. The participants were completing a master's degree through part-time weekend courses. In the first semester, the participants enrolled in six courses: science methods, science curriculum, science content, English for graduate students and a seminar in science education, as well as the Nature of Science course that is the focus of this study.

Description of the PCK-Based NOS Course

The Nature of Science Course (NOSC) is an elective course of the Master of Education in Science Education program at a University in Bangkok, Thailand. This course lasted 15 weeks with 2 hours of instruction every Saturday. The NOSC was developed from a previous History and Philosophy of Science Course. The major goal of the course therefore was to enhance science teachers' understandings of NOS and its teaching. This meant that NOS was considered to be the content for the course. PCK for teaching NOS suggested by Haunscin et al. (2011) was used as a conceptual map to design learning activities in the course. In an attempt to accomplish the major goal, the course was therefore structured in line with the PCK components as shown in Table 1; (a) orientations to teaching NOS, (b)

Table 1 Outline of PCK-based nature of science course

Week	Topics	Learning activities
1	Course introduction Prior knowledge about the nature of science and its teaching	Discuss in-service teachers' expectations and Course Syllabus
		Complete open-ended questionnaire about the NOS, think aloud and share their ideas about NOS.
2	NOS aspects (Observation vs. Inference/ Empirical nature of science/Theory-ladenness /Science vs. Technology)	Participate in non-content-specific activities; Mystery Cub #3 and #4 which described in details in Lederman and Abd-El-Khalick (1998).
3	NOS aspect (Tentativeness/Evidences in science/Blend of logic and imagination/ Science vs. social and historical milieu)	Read biography of scientists in the past; Archimedes and Galileo.
4	NOS aspects (Scientific knowledge) Teaching science concepts, principles, theories, and laws	Participate in Jigsaw cooperative learning
		Example teaching about light bulb circuits, gas laws and collision theories
5	NOS aspects (Scientific world view/Scientific inquiry/Scientific enterprise)	Conclude and summarize understanding of NOS as was learned from Weeks 1–4
6–7	NOS aspects in science curriculum and international perspectives	Review NOS from science curriculum standards and research articles
		Analyse trends and issues in the NOS and compare to the NOS issues in Thai science curriculum standards.
8–9	Assessment of students' understanding of NOS	Design assessment tools to probe students' conceptions of NOS
		Report and discuss the results of using assessment tools
10–12	Teaching strategies of the NOS (Implicit/ Explicit Instruction/Historical approach)	Read and discuss academic and research articles about NOS and its teaching
13–14	Integrations of PCK components into lesson plans	Design lesson plans in order to promote students' understanding of NOS
15	Conclusions	Complete post-instruction questionnaire of NOS
		Reflect on their learning and offer feedback on teaching and learning activities in the Nature of Science Course through a semester.

knowledge of science curriculum, (c) knowledge of students' conceptions about NOS, (d) knowledge of teaching strategies, and (e) knowledge of assessment of students' learning about NOS. Learning activities focused on how science teachers view NOS, understand the position of NOS in curriculum standards and materials, set NOS as a student learning outcome, understand students' conceptions and difficulties in NOS, design teaching strategies and materials, and assess students' learning about NOS. The science teachers were provided with a set of opportunities based on the metacognitive approach with an emphasis on reflective and explicit teaching strategies. These strategies were intended to help science teachers discuss and deeply reflect on the various aspects of NOS. The in-service science teachers were encouraged to discuss and reflect on NOS aspects both in international and national contexts through various activities. These activities included analysing the aspects of NOS in science curriculum standards, designing alternative tools to assess students' understanding of science and reporting its results, reading academic and research articles and scientists' biographies, experiencing NOS instruction with science activities in both integrated and non-integrated science content, analysing trends of research in NOS, and planning daily lessons related to NOS.

Data Collection

Data was collected throughout the entire semester in which the participants were enrolled in the Nature of Science Course. Data sources included pre- and post-questionnaires, weekly electronic journal entries by participants, course assignments, and field notes. According to the first research question, an open-ended questionnaire was used as the primary data, consisting of seven questions; six items related to the understanding of NOS and one item related to orientations towards teaching NOS. The items were adapted from published research studies. The questionnaire relating to teachers' understanding of NOS specifically focused on the definition of science (Abd-El-Khalick and BouJaoude 1997; Lederman 2002); characteristics of science (Haidar 1999), differences between scientific law and theory (Akerson and Donnelly 2008; Haidar 1999); tentativeness of scientific knowledge (Haidar 1999); scientific inquiry (Abd-El-Khalick and BouJaoude 1997; Haidar 1999); and the interaction between science, technology, and society (Yalvac et al. 2007). Validity of the questionnaire was enhanced by reviewing the content with panels of experts at the university and experimenting with other groups of Master's degree students. All participants completed the questionnaire in the first and last week of the course. As a research tool, the questionnaire enabled the researcher to compare participants' understanding of NOS before and after studying the PCK-based NOSC. The questionnaire was also used by the course instructor to motivate the participants to recognise the aspects of NOS that they themselves may find challenging.

For the second research question, which aimed to examine participants' learning about NOS and orientations to teaching NOS through the course, the participants' journal entries were the primary data source. The participants were asked to reflect upon their learning in the weekly journals. The guided questions in the journal were as follows: What have you learned from the course?; What do you still not understand?; What are you going to study further?; and What are your suggestions about today's teaching and learning activities? As the course progressed, the participants sent their journal to the instructor by email or Max@learn, an online-course website. In addition, classroom discussions about NOS aspects were carefully monitored using field notes.

Data Analysis

In order to answer the first research question, the data from pre- and post-instruction questionnaires were analysed first. The participants' responses to the questionnaires were compared to identify changes in their understandings of NOS and teaching orientations. Content analysis was applied both aspects, but also different themes and categories by adopting Abd-El-Khalick and Akerson (2009)'s categorization of NOS. As a result, the participants' responses were placed into one of three categories: 'informed', 'partially informed', or 'naive'. The responses were categorized as 'informed' if the participants' responses indicated that their views were consistent with contemporary constructivist views of NOS in which observation is viewed as theory laden and science is viewed as a set of socially negotiated understandings of the universe. If the responses were partially compatible with constructivist views of NOS, they were categorized as 'partially informed'. If the responses were completely inconsistent with constructivist views of NOS, which science is viewed as a purely objective process for determining knowledge and understanding about the natural world, they were categorized as 'naive'. After the initial categorization, the responses were categorized into sub-categories in order to see patterns and key issues. Secondly, orientations to teaching NOS were analysed by using the PCK framework suggested by Magnusson et al. (1999). The teachers' responses in pre- and post-instruction questionnaires were categorized according to nine different orientations: (1) process, (2) academic rigor, (3) didactic strategies, (4) conceptual change, (5) activity-driven, (6) discovery, (7) project-based science, (8) inquiry, and (9) guided inquiry. The results of participants' understanding of NOS and orientations to teaching it from both the beginning and the end of the course were compared in order to show the extent to which the participants developed their understandings.

According to the second question, which attempted to examine participants learning about NOS through the course, data from field notes, journal entries and worksheets were assembled. From these data, the researcher identified specific events and activities that were either representative of the participants' understanding of NOS and orientations to teaching NOS, or constituted a significant event in the course in relation to their understanding. The incidents that related to understandings of NOS taught in each week were summarized. The researcher focused on the identification of trends or patterns in the statements made by the participants, and developed categories and their properties on the basis of the data through an iterative process. This process was done by comparing the consistencies and differences between properties of tentative categories and incidents. If a new incident did not fit with any categories, the prior categories would be refined or a new category would be generated. Finally, the data from different sources were constantly compared to each other, as well as with main points related to participants' understanding of NOS and orientations to teaching NOS.

Findings

Changes in Their Understandings of NOS

Definitions of Science

According to its definition explained by contemporary science educators, science is viewed as both a body of knowledge and a way of generating knowledge. In order to respond to this definition, participants were asked the question "What is science?" Prior to the instruction, the majority of them held a partially informed understanding of the definitions of science. Of these in-service teachers, some viewed science as a product of knowledge for the purpose of explaining natural phenomena, and considered that science exists around them and can be used to explain nature. Other teachers believed that science is a subject that can assist students to develop their skills by systematically observing and forming hypotheses to answer questions about nature. Still others believed that science consists of teaching people the practice of logical and reasonable argument. For example, one of the in-service teachers noted that “[science] is a subject dealing with reality, nature around us, and it can be proved.” Another student mentioned that “science is a discipline that helps people to think logically, reasonably.” There were five in-service teachers holding a naive understanding about this aspect of NOS. These teachers thought that science is a search for reality in the external world through the use of rigorous scientific methods.

Through engaging in the PCK-based NOS course, in-service teachers’ understanding of the definition of science improved from pre-instruction to post-instruction (as shown in Table 2). In the post-instruction responses, approximately half of the in-service teachers held informed understandings of this target NOS aspect. They explained more details about relation to NOS. They were also able to articulate that science is not only a body of knowledge but also a process of generating knowledge. Furthermore, they believed that science requires empirical evidence in generating scientific knowledge. For example, one of them stated that

> Science is explaining natural phenomena through logical thinking and empirical evidence-based scientific processes such as posing questions, formulating hypotheses, collecting data, making conclusions, then coming up with the conclusions to be concepts, laws or theories in explaining natural phenomena. (Patra’s post-questionnaire)

Even though no in-service teacher held naive views of the definition of science in the responses of the post-instruction questionnaire, 48% of them still had only a partial

Table 2 Number and percentages of participants holding naïve/partially informed/informed understandings of NOS (n=25)

NOS aspect	Pre-instruction			Post-instruction		
	Naïve	Partially informed	Informed	Naïve	Partially informed	Informed
Definition of science	5 (20%)	19 (76%)	1 (4%)	0 (0%)	12 (48%)	13 (52%)
Empirical evidence of scientific knowledge	15 (60%)	8 (32%)	2 (8%)	3 (12%)	9 (36%)	13 (52%)
Laws and theories	24 (96%)	1 (4%)	0 (0%)	5 (20%)	7 (28%)	13 (52%)
Tentativeness	0 (0%)	25 (100%)	0 (0%)	0 (0%)	11 (44%)	14 (56%)
Scientific inquiry	3 (12%)	20 (80%)	2 (8%)	2 (8%)	7 (28%)	16 (64%)
Interrelationships of science, technology and society	4 (16%)	21 (84%)	0 (0%)	0 (0%)	16 (64%)	9 (36%)
Total	51 (34.0%)	94 (62.7%)	5 (3.3%)	10 (6.7%)	62 (41.3%)	78 (52.0%)

understanding of this aspect. Of this group, five viewed science only as a process of generating knowledge, while eight others described science as a body of knowledge. Several teachers believed that science is a collection of facts that explains the world with little or no elaboration. For example, one of the in-service teachers noted that science is a study of natural phenomena and consists of knowledge and facts.

Empirical Evidence of Scientific Knowledge

In the aspect of empirical evidence of scientific knowledge, participants were asked the question “What are the differences or similarities between scientific knowledge and knowledge of other disciplines?” Prior to the instruction, several in-service teachers failed to refer to empirical NOS as a major distinguishing feature. Rather, many of them believed that scientific knowledge was different from other disciplines because it involved a simple step-by-step processes for experimentation. A majority of in-service teachers held naive understandings in which, unlike other disciplines, scientific knowledge is derived from a rigorous scientific method. In their views, scientific knowledge is different from that of other disciplines due to its own process of generating knowledge. Even though some of them held partially informed views about the empirical evidence and how it is used to establish scientific knowledge as a distinctive feature separating science from other disciplines, they did not elaborate on this in detail. Interestingly, five of the in-service teachers with naive understandings relied heavily on experimentation within science. When thinking of science, they consistently referred to scientific experimentation as a necessary prerequisite to claiming the validity of scientific knowledge.

Several desired changes in interpretation of empirical evidence of scientific knowledge were identified in the responses to post-instruction questionnaires. As made clear in the percentages of informed post-instruction views of the NOS aspects, these changes showed that about half of in-service teachers gave more detailed responses and indicated empirical evidence as a key aspect separating scientific knowledge from knowledge of other disciplines. One of the in-service teachers stated that “[scientific knowledge] is different from others disciplines because it needs evidence to be confirmed and verified, leading to conclusions.” Some participants also considered the role of personal beliefs and prior knowledge, such as logical thinking and imagination, and to be connected to the empirical evidence as in the generation of scientific knowledge. They noted that “scientific knowledge is different from others because it is a knowledge which can be explainable, logical, and empirically evident.”

Laws and Theories

The in-service teachers were asked to identify differences or similarities between laws and theories. Interestingly, no in-service teacher held an informed view that scientific laws tend to describe relationships of two or more things while theories are to explain these relationships or natural phenomena. Almost all in-service teachers held the naive view that laws are mature theories. Of the in-service responses, nearly 80% indicated the interchangeability of the two types of scientific knowledge. In their understandings, a law is a reality that cannot be changed while theory is a working hypothesis that can be changed. For example, one of the in-service teachers stated that “law is a reality in science. It is true forever without any arguments, and law can thus not be changed. Theory is a reality in science but it can be changed if there is some evidence or argument.” Two other in-service teachers believed that when a theory has been proven and tested to be true, it can become law. Another two in-service teachers indicated the reverse process, that laws become theories.

At the end of the NOS course, there were some changes in the in-service teachers' interpretation of the NOS aspect of laws and theories. Around half of them held more informed understandings, indicating differences of scientific laws and theories in terms of their roles in science. They reached the realization that law is scientific knowledge describing patterns or relationships of two or more things while theories tend to explain these patterns, relationships or phenomena in nature. In-service teachers also added more detail to their explanation of the similarity between these two kinds of knowledge, which relate to the tentativeness of scientific knowledge. However, there were a number of in-service teachers that still held partially informed understandings of laws and theories. Five in-service teachers at the end of the course still held naive understandings illustrated by a belief in a hierarchical relationship between laws and theories.

Tentativeness of Scientific Knowledge

With regard to tentativeness of science, participants were expected to develop an informed view in that scientific knowledge can be changed if there is more evidence, rational argument and scepticism. Prior to the instruction, all in-service teachers held a partially informed understanding of the tentativeness of scientific knowledge, that is to say, scientific knowledge can change. In their view, evidence was regarded as the central factor contributing to the tentative nature of science. They appeared to believe that this factor resulted in the substitution of old knowledge with new knowledge. All of them made mention of the elaboration of the prior knowledge. Some teachers stated that scientific knowledge is subject to changes because of technological advances, and noted that it can be changed if the new knowledge provides more effective explanations. Additionally, from in-service responses, subjectivity and creativity were not regarded as important factors contributing to the tentative nature of scientific knowledge.

Changes among in-service teachers' understanding of this tentative aspect of scientific knowledge between pre- and post-instruction were significant. By their response in the post-instruction questionnaire, 56% of in-service teachers held more informed understandings while 44% still held partially informed understandings in this aspect. However, they seemed to shift their beliefs from thinking only of evidence or technology as causes of changes within scientific knowledge, towards a consideration of imagination and logical thinking. They also added more details and gave examples in their explanations. They believed that scientific knowledge can not only be changed, but also can be renewed or elaborated upon. Some of them articulated this view explicitly:

> [Scientific knowledge] can be changed because science cannot explain all matter. There are some limitations such as time, situation, or evidence. At certain points, science needs imagination and creative thinking to predict, for example, the developments of atomic structure by John Dalton, J.J. Thomson, Rutherford, and Neil Bohr. These scientists gradually developed atomic models from one to one, and they gradually elaborated the previous model. (Kannadit's post questionnaire)

Scientific Inquiry

In order to probe in-service teachers' understanding of the nature of scientific inquiry, they were asked how scientific knowledge is developed. Prior to the instruction, only 2% of in-service teachers held an informed view that science is an inquiry which demands evidence, and a blend of logic and imagination. Eighty percent of them held a partially informed understanding of this aspect. Within this category, the in-service teachers could be further divided into two groups. The first group were in-service teachers who believed that scientific knowledge was derived from scientific skills and attributes, such as observation skills, experimentation skills, curiosity and creative thinking. The other group consisted of in-service teachers who believed that scientific knowledge could only be derived from the use of scientific methods. In their interpretation, scientific methods including observing, posing questions, formulating hypotheses, carrying out experiments and arriving at conclusions constituted the systematic process that resulted in about scientific knowledge.

By the post-instruction, in-service teachers held better understandings of scientific inquiry. More than half of them held an informed understanding, illustrated by their belief that scientific knowledge came about not only through scientific methods but also because of the subjectivity and creativity of scientists. Most in-service teachers described their answers in more detail and offered examples. One of them stated that

> There are many ways to gain scientific knowledge. It includes experimentation based on scientists' curiosity; making observation of natural phenomena, then coming to conclusions; and observing and categorizing things such as the division of living things. From this, we are able to know how many categories of living things exist, what important characteristics are for each group of living things, and how they behave. Integrating the imagination of human beings with evidence is an essential process, and explains how a discovery such as a fossil can explain something they have never seen, such as dinosaurs. (Nina's post-questionnaire)

Interrelationships of Science, Technology and Society

For this aspect, in-service teachers were asked whether science, technology and society are interrelated and how. Interestingly, all in-service teachers held partially informed understandings of the interrelationship of science, technology and society, but these interrelationships were considered linear. They recognized the interaction between science, technology and society in certain ideas, such as the belief that science is the basis of knowledge to build technology, and that the use of technology is used to solve or construct things makes people's lives better and contributes to their overall well-being. While some participants also considered that technology helped to generate scientific knowledge, the potential influences of social and cultural factors on scientific practice were overlooked by all in-service teachers. They dismissed the role of science as a social activity. For example, as one in-service teacher noted, "They are related. As science is developed, so technology is developed and society will then be changed." However, distinguishing between science and technology appeared to be a difficult task for them. Additionally, four in-service teachers expressed naïve understanding, in other words, that technology is simply applied science.

The post-instruction responses indicated that many in-service teachers held an improved understanding of the interrelationships between science, technology and society. Of these responses, there were no naive understandings. Sixty-four percent of in-service teachers who had partially informed understandings gave more details and examples in their explanation of the interrelationship between the three aspects. They did not view science and technology as possessing a linear relationship, but instead that they interact with one another. Thirty-six percent of them viewed science, technology and society as a complex relationship. They were aware of the influence of social and cultural factors on the direction of scientific and technological enterprise. One in-service teacher noted that

> Science, technology and society are interrelated since, for example, science and technology bring new knowledge and innovations respectively to society. In the meantime, society also requires knowledge and new innovations. This requirement will direct scientists search for new knowledge for developing new technologies. Scientists have a role of making decisions in society, which in some cases will need an explanation. (Jurina's post-questionnaire)

Changes in Orientations to Teaching NOS

As shown in Table 3, the data analysis indicated that prior to the NOS course instruction, in-service teachers' orientations to teaching NOS were diverse and distributed among various categories. The three orientations with the highest response rates were project-based science, guided inquiry and process, respectively. Thirty-six percent of in-service teachers relied heavily on a project-based approach, with the teaching of NOS designed to develop students' everyday problem-solving abilities and understandings of scientific methods. In-service teachers believed that by providing situations to develop these abilities and understandings, they would ask students to carry out their own projects by observing everyday phenomena, formulating questions and investigating these questions on their own. Twenty-four percent of in-service teachers viewed the process aspect as the goal of teaching NOS. They believed that students must have scientific process skills and have the ability to think scientifically as scientists do. They believed that if they were to provide students with hands-on activities, the students would eventually accomplish this goal. Sixteen percent of in-service teachers' orientation to teach NOS was through guided inquiry, with teachers embracing their roles as facilitators to help students investigate problems, perform experiments, and come to conclusions. In their view, teachers must also prepare and provide tools and apparatus in learning activities.

Additionally, all orientations to teaching NOS mentioned above were then categorized into sub-groups as explicit or implicit instruction. Analysis indicated that all in-service teachers' orientations to teaching NOS were framed by implicit instruction. They believed that the students can instinctively learn scientific process skills, scientific thinking, scientific methods and the attributes of scientists when carrying out experiments. For example, one of the in-service teachers suggested that

> Learning activities should provide students with opportunities to use their science process skills in investigating scientific phenomena. For example in teaching of photosynthesis, teachers have to encourage students to ask questions why light is needed for plants. Doing this helps students formulate problems and solve their own problems by using science process skills. (Sunanta's post- questionnaire)

Relative to their pre-instruction views, the post-instruction views of in-service teachers showed major changes for orientations to teaching NOS. Interestingly, by the end of the course, the greater change came in the inquiry orientations. More than a half of in-service teachers shifted their orientations to teaching NOS from science as a process and discovery approach towards an inquiry-based approach. The in-service teachers viewed science as a

Table 3 Number and percentages of participants' orientations of teaching NOS (n=25)

Orientation to teach NOS	Pre-instruction	Post-instruction	Examples of responses
Project-based science	9(36)	3(12)	The activity that I believe works best for students is a science project, as it will help students learn the nature of science without realizing what they have learned. Reasonable, open-minded, decent and logical, these are characteristics of the nature of science.
Process	6(24)	3(12)	Provide students with a learning environment to develop their scientific process skills such as observing, formulating hypotheses, calculating, etc.
Guided inquiry	4(16)	2(8)	Learning activities should focus on scientific processes. For example, in teaching photosynthesis, teachers should provide students with reasons to be skeptical of whether light is one of the factors in the growth of plants. The teachers may then set two conditions of plants growing with and without light. The teachers can then ask students the differences between these two, help them formulate questions and let them discover the answers.
Activity-driven	3(12)	0(0)	To understand the nature of science, students must participate in hands-on activities and have direct experiences. If we want students to understand the nature of science, they must do so by themselves.
Discovery	3(12)	1(4)	Each student should be allowed to ask questions, based on his or her experiences and observation, that they are most curious about. Let students find the answers to the questions they want to know.
Inquiry	0(0)	15(60)	Teachers motivate students' thinking by asking questions such as why and how these [natural] phenomena happen. The teachers should let students answer these questions by themselves. Students may have different answers but they must have evidence to prove their answers. As a result, the teachers should provide students with opportunities to carry out inquiry.
Conceptual change	0(0)	1(4)	For example, in teaching of components of the earth, 1) probing student understandings of the earth by asking what they think about when saying the word "earth," 2) explaining ancient beliefs about the earth, 3) challenging whether these beliefs are correct or not, and why they think so, 4) providing information and evidence such as satellite pictures, 5) helping with conclusions through the use of evidence, and 6) encouraging overall conclusions.
Academic rigor	0(0)	0(0)	–
Didactic	0(0)	0(0)	–

form of inquiry, and that the goal of teaching NOS is to develop students' understanding of scientific inquiry. Many of the in-service teachers wanted the students to observe natural phenomena, pose their own questions, investigate these questions and come to conclusions based on concrete evidence. Of those with an inquiry orientation approach, 47% of in-service teachers considered that inquiry must be combined with explicit instruction. They also wished to target aspects of NOS explicit in their instruction:

> Students should be supported to perform inquiry in order to construct knowledge by themselves. Teachers may set situations similar to those of scientists, then let students carry out activities and take on their role as a scientist. One thing teachers need to do is make NOS aspects explicit, and help students learn these outwardly. This will help students better understand NOS. Furthermore, in teaching activities, the teacher should frequently ask students questions in order for them to reflect on their learning and thinking. This will help students to get to know their own patterns of thinking, and teachers can check whether or not it meets their teaching objectives. The questions should be related to NOS aspects. (Jarin's post-questionnaire)

Learning through Elements of a PCK-Based NOS Course

To answer the second research question "In which ways did in-service science teachers develop their understanding of NOS and orientations to teaching NOS in the context of the PCK-based NOS course?", the processes of in-service teachers' learning about NOS that emerged from gathered data are addressed. These processes described below include reflecting on their learning about NOS, role modelling, participating in content embedded and non-content embedded NOS instruction, reading articles about scientists' biographies, and academic and research articles about NOS and its teaching, and designing alternative tools to assess students' understanding of NOS.

Reflection on Their Learning about NOS

Many in-service teachers viewed their learning as a result of reflecting on their own interpretations. Through the PCK-based NOS course, in-service teachers had many opportunities to reflect on their own views about NOS and its teaching. These opportunities included completing pre-instruction questionnaires and reflecting on their prior knowledge of NOS and writing weekly journal entries and discussions with peers. From analysing their journal entries, it appeared that completing the questionnaire in particular led in-service teachers to problematize their own understandings of NOS. At the beginning of the course, the in-service teachers were asked to complete an open-ended questionnaire about the nature of science and were then challenged to think aloud and share their ideas. This activity motivated the in-service science teachers to realize their possibly naive understandings of NOS. One reflected that:

> Even though this is the first period, it has made me more aware and made me ask questions of myself. Am I a good teacher? Why did I hesitate to answer when completing the questionnaire if the all questions are basic, and did not seem difficult? This causes me to rethink my role as a teacher, and to focus on the nature of science. (Siri's 1st week journal)

Completing a questionnaire prior to the instruction also motivated the in-service science teachers to think about how to teach NOS. Many in-service teachers asked the instructors how science teachers teach NOS to students. This question was reflected in their first week journals, for example:

> I don't have much experience in teaching the nature of science. I cannot imagine how to teach it. To help students understand the nature of science, what else can I do in addition to science projects? Does 'learning by doing' work? What I have taught in my class is setting hands-on activities for students and letting them design investigations by themselves. Is this a correct way to teach the nature of science?' (Jarin's 1st week journal)

Role Modelling

A majority of in-service teachers frequently viewed the course instructor's teaching as their model for teaching NOS. They noted that constructivist-based teaching by the instructor had served as an inspiration for their teaching of NOS in their own classroom. Through role modelling, in-service teachers assumed their role as high school students while the NOS course instructor acted as a school science teacher. Most of the class sessions in role modelling ended with explicit critiques and discussion about NOS aspects and teaching, particularly focusing on student conceptions of NOS, teaching strategies, and instructional media and assessment methods. In their view, they could directly experience learner-centred teaching and considered that the role modelling helped them experience learner-centred teaching first-hand. Afterwards, the in-service teachers felt they better understood how to teach NOS. For example, in Week 4 during which the activities were air pressure and light bulb activities addressing construction of scientific knowledge, one in-service teacher noted that

> What I've learned this week is how to help students construct their own concepts. By engaging in the light bulb activity, I've learned the word 'conductivity' and 'resistance'. These words came up after doing the activity. This is what scientists do. It's not from what you told us but from ourselves who can explain the meaning of conductivity. I think this is a good activity. I will use this activity with my students. (Jane's 4th week journal)

In-service teachers' reflection on the instructors' role modelling showed that changes had occurred in their understanding of and approach to NOS, especially in the aspects of laws and theories. Their broadened view of NOS indicated that they now saw for example the different roles of scientific laws and theories. One of 15 in-service teachers who changed their view reflected that

> We've learned Ohm's law from a very simple activity. There were just only light bulbs, batteries and wires. We can come up with the equation V = IR by ourselves. It's brilliant. Now we know how scientific laws are constructed. You helped us relate variables and lead to formulate a law [Ohm's law]…In the balloon activity [air pressure activity], you [the instructor] asked us why the balloon is inflated. It's because of the heat. The more heat, the faster gas molecules move. It causes gas molecules to have more chance to collide with each other and push the balloon out. This explanation is the kinetic theory of gases. Theories explain how this phenomenon occurs. So, to come up with theories we need to use our logical thinking and imagination based on evidence we observed.

Participating in Content Embedded and non-content Embedded NOS Instruction

Analysis of classroom discussion and reflective journals indicated that in-service teachers valued both types of activities in the NOS course; content embedded and non-content embedded NOS instruction. Non-content embedded NOS instruction seemed to promote in-service teachers' understandings of NOS, while content embedded NOS instruction could promote both understanding and teaching of NOS. For example, in the second and fourth weeks, in-service teachers were provided with the non-content embedded NOS activities of the Mystery Cube #3 and #4, Tricky Track, Watering Machine, Old and Young Women activities which are described in detail in Lederman and Abd-El-Khalick (1998). These activities were designed to address several aspects: differences between observation and inference; that science begins with asking questions about the world; that scientific knowledge is empirically based and theory-laden; and the relationships between science and technology. Reflections on their learning through these activities indicated that 12 in-service teachers had more informed understandings of these aspects of NOS. In the Mystery Cube activity for example, the following reflection demonstrated in-service teachers' learning about target NOS aspects, and illustrated how they can benefit from participating in engaging, non-content embedded NOS activities:

> What I've learned from this activity is a better understanding of how scientific knowledge is generated. Previously, I had understood that science needs only to rely on scientific methods, which are posing a problem → formulating hypotheses → performing experiments → making conclusions. From the activity however, scientific knowledge is derived from observation, asking questions, searching for and collecting evidence and making conclusions. We can predict the answers by carefully observing and relating all data to develop the meanings. (Patra's 2nd week journal)

An example of in-service learning from the Old and Young Women activity is shown below:

> I can differentiate between observation and inferences from pictures the instructor showed us. When the instructor asked 'what do you see,' most of us answered that it's a bird track, which is an inference, not an observation. The inference results from bringing observational data in relationship with prior knowledge. If it is an observation, we must explain that it's a black spot, describe its shapes…that there are…spots. (Siri's 4th week journal)

Additionally, in the content-embedded NOS instruction, the in-service teachers had learned how to teach NOS and became satisfied with learning activities. Since this instruction integrated scientific content with teaching strategies that made in-service teachers clearly see all the necessary processes of teaching, they were very impressed. One of them noted that

> The instructor used a variety of learning activities which I can adopt in my class. I didn't expect that the instructor would use teaching strategies as if we were school students, as we are at a masters degree level. I like this kind of teaching. There are examples and demonstrations motivating students to engage with the lessons. We gained a better understanding because you are able to make the abstracts become concrete. So if we understand better, we can teach our students more effectively. (Busa's 4th week journal)

Reading Articles about Scientists' Biographies

While there were some reflections that indicated informed progress from a learning activity, it was found that each week, journal entries often indicated some degree of confusion with respect to aspects of NOS. The in-service teachers gradually shifted their naive understandings to informed understandings through a series of activities. The in-service teachers were assigned homework relating to biographies of Archimedes and Galileo. Two biographies were in Thai from the website of the Department of Science Service (http://siweb.dss.go.th/Scientist). Prior to week three, they were asked to analyse and reflect upon what they had learned from the readings and then discuss these topics in class. Many in-service teachers mentioned that reading and discussing the paper had improved their understanding of the impact of scientific processes and social and cultural factors on scientific endeavour. They also elaborated on their understandings of scientific inquiry by focusing not only on scientific methods, but also on the subjectivity of scientists. They described the importance of desirable attributes of scientists to their scientific inquiry, including meticulousness, organization, sensitivity towards accurate collection and recording of data, and awareness of the theory-laden nature of observation and interpretation of data. As one particular in-service teacher stated:

> Galileo accomplished scientific knowledge because of his skepticism and curiosity. He brought his observations together with his prior knowledge, and then proved them through scientific processes. He then disseminated what he found to the public. I think his thinking was outside of the box and creative. He was confident and did not simply believe things without proof.' (Waran's 3rd week journal)

Reading Academic and Research Articles about NOS and its Teaching

Reading articles followed by discussion about NOS instruction among the entire class had an impact on in-service teachers' orientations to teaching NOS. At the beginning of the course, many in-service teachers viewed teaching NOS as project-based learning. They believed that NOS should be taught through an implicit approach by focusing on the development of students' science process skills and scientific attitudes. When they experienced activities in the NOS course, including activities in weeks ten to 12, in-service teachers became aware of the explicit inquiry instruction approach to teaching NOS. The in-service teachers were asked to work in groups of five to elaborate their understanding of NOS by reading articles including; *Focusing labs on the nature of science* (Colburn 2004), *Keys to teaching the nature of science* (Mccomas 2004), *Understanding the nature of science through evolution* (Narguizian 2004), *Revising instruction to teach nature of science* (Lederman and Lederman 2004), and *Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science* (Khishfe and Abd-El-Khalick 2002). This activity could evidently expand in-service teachers' understandings of how NOS should be taught in science classrooms. They saw alternative examples of teaching NOS and became aware of constructivist views of teaching and learning of the NOS. For example, as one participant explained,

> In teaching NOS, we first of all have to be familiar with students' understandings of NOS, and how they learn it. This will help us prepare activities appropriate to their learning. We have to motivate their thinking, and let them perform the activities by themselves. It is important for teachers to ask them questions. I think that is what is most important. Asking higher order thinking questions can enhance students' analytical thinking. (Waran's 7th week journal)

Additionally, after reading all of the articles, in-service teachers viewed asking students questions as a key element of helping students understand NOS. They believed that teachers should employ higher-order thinking questions, for example “how,” “why” and “if-and-then-therefore” questions. These kinds of questions can help students think about and consider the elements of NOS in a logical and critical manner.

Designing Alternative Tools to Assess Students’ Understanding of NOS

In weeks six to nine, the in-service teachers were asked to work in groups of five to review research articles and science curriculum standards. Each group chose one of the five science education journals, including *International Journal of Science Education*, *Journal of Research in Science Teaching*, *Science Education*, and *International Journal of Science and Mathematics Education*. They were asked to analyse trends and issues in NOS and compare them to the NOS issues in Thai science curriculum standards. In-service teachers were then asked to design assessment tools to probe students’ conceptions of NOS. They used the tools to collect data in their own classroom and then analysed and presented their findings to the class. The in-service teachers observed that all students have their own understanding of NOS, which may or may not be correct. Furthermore, designing assessment tools enhanced the teachers’ understanding of NOS. Since in-service teachers had to review and clarify their own understanding of NOS prior to designing the tools, they discussed NOS aspects with their peers in order to ensure that they held contemporary views of NOS. When analysing students’ conceptions of NOS, in-service teachers generally used criterion-oriented analysis based on the reviewed literature. This analysis process also fostered their awareness and understanding of NOS.

Conclusions, Discussion and Implications

This research study contributes to a broader understanding of the characteristics of a PCK-based nature of science course (PCK-based NOS course), and its impact on the development of in-service teachers’ learning about NOS, as well as their orientations to teaching it. The results indicated that a PCK-based NOS course helped in-service science teachers develop deeper and more informed understandings of NOS and the related teaching orientations. The results also showed that in-service teachers broadened their understanding of all NOS aspects. The majority of in-service teachers had a more informed understanding of NOS in the post-instruction questionnaire than in the pre-instruction questionnaire. Prior to the instruction, many in-service teachers held naive views of the target aspects of NOS, especially in the aspects of law and theory, and scientific knowledge. Almost all in-service teachers possessed a naive understanding of the NOS aspects of law and theory, whereas more than 70% of them held an informed understanding of the NOS aspect of interrelationships of science, technology and society. Compared with in-service teachers’ understanding of other emphasized aspects, their views of the law and theory aspect seemed more resistant to change. The greater change came in the aspect of scientific inquiry. As they engaged in the NOS course, most in-service teachers appeared to have developed his or her understanding of NOS in all emphasized areas. The development of in-service teachers’ understandings of NOS in this context was consistent with those suggested in the literature for supporting teachers’ better understanding of NOS (Akerson et al. 2000; McComas et al. 1998; Schwartz et al. 2004). In addition, the in-service teachers shifted their orientations to teaching NOS from an implicit science process and discovery approach towards an explicit inquiry-based approach. They learned the sequences of explicit inquiry-based teaching strategies, specifically that effective teaching activities should begin by motivating students' interest, eliciting prior conceptions of NOS, asking students' questions related to target NOS aspects, and that students should have a chance to carry out hands-on activities. However, not all the in-service teachers could change their naive understandings to informed ones, especially in the case of laws and theories. It is argued that 15 weeks of the course may not be enough to promote their understanding of NOS and the retention of NOS. As suggested by Akerson et al. (2006), science teachers may not retain their understandings of NOS. There is a need to encourage them to attain a cognitive position to retain their improved NOS views.

While this study aims to examine the development of in-service teachers' understanding of NOS and their orientations to teaching NOS, it also provides science teacher educators with a course framework designed to support the development of in-service teachers. This in turn implies that science teacher educators should focus on using PCK as a framework to develop NOS courses. Based on this finding, this study supports ideas of Haunscin et al. (2011), which state that NOS is considered subject-specific content, and that the teaching and learning of NOS is therefore unique and specific to particular contexts. PCK for teaching NOS is useful for developing science teacher education programs in that it can be used to set goals, improve instructional strategies, and align assessment in order to enhance teachers' understanding of NOS and its instruction. This suggests that a PCK-based NOS course enabled the in-service teachers to consider various aspects of NOS according to PCK components including learning outcomes, NOS in science curriculum, student learning, conceptions of NOS, constructivist-based teaching strategies, assessment of student learning, and how to make certain features of NOS explicit to students.

In particular, the development of in-service teachers' understandings and orientations to teaching NOS resulted from explicit discussions. The in-service teachers had opportunities to explicitly reflect on their own interpretation of NOS and its teaching. This allowed them to consider the fundamental ideas about certain aspects of NOS, as well as the goals of teaching and learning NOS. This finding is in line with Abd-El-Khalick and Akerson (2009) who point to the impact of metacognition on science teachers' understanding of NOS. This finding also supports the idea that metacognition should be embedded in various contexts (Akerson et al. 2006). As found in this study, metacognition is embedded in a series of activities including role modelling, analysing research articles and documents, engaging content- and non-content embedded NOS instruction, reading scientists' biographies and designing assessment tools. Ostensibly, one activity cannot stand alone, but each activity must instead support one another. It is argued that metacognition should be continually encouraged in all activities. For example, in the case of the aspects of laws and theories, reflection on activities after content-embedded instruction was not enough to change the views of in-service teachers. The in-service teachers must be encouraged to elaborate their understandings of this aspect through reflection on other activities such as non-explicit, content-embedded instruction.

Unfortunately, this study was limited in the sense that in-service teachers were rarely provided with opportunities to implement NOS instruction in their own class, and subsequently reflect on their teaching practice. As a result, if the in-service teachers are given opportunities to develop their own ideas about NOS, this will likely allow them to tie theoretical issues to classroom experiences, and vice versa. They will be encouraged to think about their views of NOS in a specific context that might be more meaningful to them, and then they may be able to construct and reconstruct knowledge bases needed for further development of their understandings of NOS. In-service teachers do not need to wait until they complete the course to bring their understanding of NOS into their teaching. Rather, they should be provided with direct experiences to transform their own interpretation of NOS by planning, teaching and reflecting on lesson and courses. In addition, ongoing support from science teacher educators is important. In-service teachers should be provided with opportunities to test their personal understandings, and refine and reconstruct these theories with meaningful support and guidance. Additionally, collaborative action research can be an alternative way to sustain and develop science teachers' understandings of NOS. Since collaborative action research can be a tool to help in-service science teachers reflect on their PCK with their peers for teaching NOS during their teaching practice (Cullen, Akerson and Handson 2010), in-service teachers can join university staffs and their peers in sharing ideas about their NOS teaching experience when carrying out active classroom research.

In order to extend this study, it is useful to follow up how the in-service teachers implement their understandings of NOS and orientations to teaching NOS from the PCK-based NOS course into classroom practice. This kind of study will provide an in-depth understanding of whether or not their understandings of NOS learned from the course are sustainable in a teaching context (Akerson et al. 2006). Additionally, future research should investigate how a PCK-based exemplary intervention impacts in-service science teachers' PCK for teaching NOS. Similarly to the study of Nilsson and Loughran (2011) in using Content Representation (CoRe) as an alternative tool to develop science teachers' PCK for teaching science, researchers may also apply this conceptual framework as a tool to develop science teachers' understanding of NOS and their PCK for teaching it. Since the CoRe involves articulating an overview of the particular content when teaching a given topic, it represents teachers' thinking about 'big ideas' or the ideas that teachers see as important for students in developing their understanding of NOS at certain grade levels. It helps teachers answer the questions of how, why and what should be taught in order to enhance student learning; for example, what a teacher intends for the student to learn about an idea, why it is important for students to know this, what else the teacher may know about this idea, difficulties or limitations related to teaching it, student opinions or other factors that may influence teaching, teaching procedures, and specific methods of ascertaining students' understanding or confusion around this idea (Nilsson and Loughran 2011). It is necessary to gather evidence of specific strategies based on PCK for teaching NOS in the growing international community of science education. Research on PCK should also be extended to examine learning and development of our own or other science educators' PCK for teaching NOS.

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