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Abstract Science teachers need an adequate understanding of nature of science (NOS) and the ability to embed NOS in their teaching. This collective case study aims to explore in-service science teachers' conceptions of NOS and the embeddedness of NOS in their teaching about astronomy and space. Three science teachers participated in this study. All participants attended the NOS workshop based on an explicit-reflective approach. They were asked to respond to the Myths of Science Questionnaire on three different occasions, i.e., at the beginning and the end of the NOS workshop and a semester after the workshop. Classroom observation, interviews after teaching, and a collection of related documents were also employed to collect data. The data were analyzed using a constant comparative method. The results revealed two important assertions. First, science teachers' conceptions of NOS are stable and resistant to change. However, an explicit-reflective approach employed in the NOS workshop, to some extent, promoted science teachers' understanding and reasoning about NOS. Second, science teachers' conceptions of NOS are not directly related to their classroom practices. With different degrees of NOS understanding, all participants taught NOS implicitly and missed most of the opportunities to address aspects of NOS embedded in the topics they taught. The implications of these findings are also discussed.

Keywords Nature of science · Pedagogical content knowledge · Science teacher · Astronomy and space · Education reform

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Introduction

Nature of science (NOS) has been underscored as a critical component of scientific literacy (American Association for the Advancement of Science 1993; National Research Council 1996). An understanding of NOS is needed to promote effective local and global citizenship (Smith and Scharmann 1999), help individuals become informed consumers of scientific information, make sense of socio-scientific issues, participate in responsible decision-making processes, and appreciate science as a part of contemporary culture (Driver et al. 1996).

Science teachers are, therefore, responsible for helping students attain an adequate understanding of NOS. To do so, science teachers themselves must first possess an adequate understanding of NOS. However, many studies have revealed that the conceptions of NOS held by science teachers are inadequate, incoherent, and fluid (Abd-El-Khalick and BouJaoude 1997; Buaraphan 2009b; Lederman 1992). Moreover, science teachers often teach NOS implicitly and expect NOS to result as a byproduct of the inquiry process, though the literature suggests teaching NOS in an explicit-reflective manner (Abd-El-Khalick and Lederman 2000; Akerson et al. 2000; Bartholomew et al. 2004; Cakiroglu et al. 2009; Schwartz and Lederman 2002).

NOS had never been mentioned in Thai science education until the national education reform began in 1999. To support the reform, the government proclaimed the National Education Act B.E. 2542 (1999) (Office of the National Education Commission 1999), which subsequently led to a proclamation of a new curriculum, i.e., the Basic Education Curriculum B.E. 2544 (2001) (Ministry of Education 2001). The new curriculum is standards based and consists of eight learning strands. Specifically, NOS is explicitly included in Learning Sub-strand 8 of the Science

Learning Strand: Nature of Science and Technology. The learning standard of the NOS sub-strand is:

> Students must be able to use the scientific process and scientific mind in their investigations, solve problems, notice that most natural phenomena have a definite period of investigation, and understand that science, technology, and environment are interrelated. (Ministry of Education 2001, p. 7)

The NOS learning sub-strand in the Thai Science Curriculum strongly focuses on student learning of scientific processes, problem solving, and science-technology-society (STS). However, hereafter, the term NOS will not only refer to scientific processes in this paper, but also it will consist of four aspects: scientific knowledge, the scientific method, scientists' work, and scientific enterprise. The important point is that since 2001, although all science teachers in Thailand have been compelled to teach NOS according to the new curriculum, the curriculum gives them no guidance on how to practically include NOS in their teaching practices.

In addition to the NOS sub-strand, there is another sub-strand that is unfamiliar to science teachers, i.e., the Learning Sub-strand 7: Astronomy and Space. It is distinguished because its content, sequence of content, and learning requirements are different from the previous curriculum, i.e., the Primary Curriculum (Revision B.E. 2533) (1990) (Ministry of Education 1992).

There are several studies that have addressed science teachers' teaching about NOS (Akerson and Abd-El-Khalick 2003; Hanuscin et al. 2010; Mellado et al. 2007; Schwartz and Lederman 2002; Trumbull et al. 2006; Waters-Adams 2006). However, studies concerning teaching NOS in a new learning strand with unfamiliar content, i.e., astronomy and space, is rare.

The central focus of this study is, therefore, to study science teachers' conceptions of NOS, conceptual development of NOS according to the NOS workshop, and the embeddedness of NOS in teaching about astronomy and space.

Review of the Literature

The literature review consists of five parts, i.e., NOS, in-service science teachers' conceptions of NOS, educational reform and curriculum change in Thailand, teaching about NOS, and NOS embedded in astronomy and space.

NOS

The NOS construct is diverse and fuzzy; there is no single, universal conception of NOS. As Schwartz and Lederman (2002) stated, "there is not a single NOS that fully describes all scientific knowledge and enterprises" (p. 207). The difficulty in defining NOS may have arisen from its complex construct, which merges several fields together. Lederman (1992) mentioned that NOS encompasses various fields, especially epistemology, which involves how scientific knowledge is generated, and the character of science. In addition, McComas et al. (1998) stated that:

> NOS is a fertile hybrid arena, which blends aspects of various social studies of science including the history, sociology, and philosophy of science combined with research from the cognitive sciences such as psychology into 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 endeavors. (p. 4)

Based on an extensive review, science teachers' conceptions of NOS can be categorized in four groups: scientific knowledge, scientific method, scientists' work, and scientific enterprise. The NOS conceptions belonging to each group are presented in subsequent sections.

In-Service Science Teachers' Conceptions of NOS

The literature asserts that many in-service science teachers hold mixed, fluid, and incoherent conceptions of NOS (Abd-El-Khalick and BouJaoude 1997; Buaraphan 2009b; Dogan and Abd-El-Khalick 2008; Haidar 1999). Science teachers' conceptions of NOS can be categorized in four major groups, i.e., scientific knowledge, scientific method, scientists' work, and scientific enterprise. The details of each group are presented as follows.

Scientific Knowledge

In various studies, the majority of science teachers studied have demonstrated naïve conceptions of the hierarchical relationship between hypotheses, theories, and laws (Abd-El-Khalick and BouJaoude 1997; Dogan and Abd-El-Khalick 2008; Haidar 1999; Rubba and Harkness 1993). In general, they believed that when a hypothesis is proven correct, it becomes a theory. After the theory has been proven true many times by different people and has survived for a long time, it becomes a law. Some teachers did not view hypotheses, theories, and laws as different types of scientific knowledge (Abd-El-Khalick and BouJaoude 1997). For many teachers, the accumulation of supporting evidence was linked with the status of hypotheses, theories, and laws (Brickhouse 1990; Dogan and Abd-El-Khalick 2008; Haidar 1999).

Regarding tentativeness in science, science teachers may be divided into two groups. The first group believed that science is stable or static, i.e., science is a collection of facts or knowledge that explains the world (Behnke 1961; Tairab 2001). Scientists, therefore, have a major responsibility to collect as much data as possible (Craven et al. 2002; Tairab 2001). In contrast, the other group believed that science is tentative or dynamic (Dogan and Abd-El-Khalick 2008), i.e., science is constantly evolving to offer a full worldview of nature (Lunn 2002).

Many science teachers possessed the uninformed conception that scientific models are copies of reality rather than human inventions (Abd-El-Khalick and BouJaoude 1997; Dogan and Abd-El-Khalick 2008). They reasoned that scientific models are copies of reality because scientists have said, or scientific investigations have shown, that they are true (Dogan and Abd-El-Khalick 2008). In a contrasting view, some science teachers, especially those who hold a constructivist view, articulated that scientific models are scientists' best ideas for representing reality rather than exact replicas of reality (Haidar 1999).

Scientific Method

Science teachers commonly perceive the scientific method as a universal, step-wise method (Abd-El-Khalick and BouJaoude 1997; Dogan and Abd-El-Khalick 2008; Haidar 1999). This perception can be attributed to a science curriculum that presents the scientific method as a sequence of steps that students must follow to reach certain, unambiguous results (Brickhouse 1990; Haidar 1999). Many science teachers regard good scientists as those who follow the fixed steps of the scientific method in their investigations (Abd-El-Khalick and BouJaoude 1997; Haidar 1999).

Scientists' Work

The polar views of NOS concerning scientists' work are theory-laden and theory-free views. For most science teachers, the development of scientific knowledge strongly depends on scientists' observations, which are always theory laden (Abd-El-Khalick and BouJaoude 1997; Lunn 2002). However, other science teachers strongly believe that scientists' observations are theory free (Brickhouse 1990; Dogan and Abd-El-Khalick 2008; Haidar 1999; Rampal 1992).

In association with the belief in a fixed-step scientific method, some science teachers overlook the role of creativity and imagination in the development of scientific knowledge. These teachers believe that scientists do not bring creativity and imagination to their investigations but rather that they merely follow the step-by-step scientific method to reach acceptable scientific knowledge (Abd-El-Khalick and BouJaoude 1997). In this sense, "creativity seems to be stereotypically dissociated from perceived scientific qualities" (Rampal 1992, p. 424).

Scientific Enterprise

The social and cultural influences on scientific enterprise are easily recognized by most science teachers (Brush 1989; Haidar 1999; Rubba and Harkness 1993). Some science teachers also add that society affects science and technology, and science and technology, in turn, affect society (Tairab 2001). In contrast, many science teachers believe in the authoritative image of scientists and, subsequently, neglect the social and cultural influences on the development of scientific knowledge (Rampal 1992).

It is, perhaps, an easy task for science teachers to recognize the interaction between science and technology: science is a knowledge base for technology; technology, in turn, influences scientific advancement (Rubba and Harkness 1993). However, distinguishing between science and technology is probably a difficult task, and many teachers regard technology as applied science (Tairab 2001).

In the Thai context, Buaraphan (2009b) discovered eight favored, uninform conceptions of NOS held by in-service science teachers: (a) scientific theories can be developed into laws; (b) accumulation of evidence makes scientific knowledge more stable; (c) scientists are open-minded without any biases; (d) scientific theories are less secure than laws; (e) the scientific method is a fixed, step-by-step process; (f) science and the scientific method can answer all questions; (g) a scientific model (e.g., an atomic model) expresses a copy of reality; and (h) science and technology are identical.

Educational Reform and Curriculum Change in Thailand

Thailand is a medium-sized developing nation that has never been colonized. The educational reform movement in Thailand arose from the so-called Asian economic crisis of the late 1990s, which highlighted an urgent need to develop the Thai people's ability to keep up with the rapid changes characterized by mass globalization (Office of the National Education Commission 1999).

Educational reform in Thailand began with the proclamation of the National Education Act B.E. 2542 (1999). The main purposes of educational reform are the following: expanding basic education, from nine to 12 years of schooling; providing education to meet learners' basic learning needs, to upgrade their skills and encourage their self-development; implementing internal and external quality assurance systems in schools and educational institutes; reforming administration and management of education to encourage full participation of local educational authorities and the local community; encouraging private-sector participation in educational provision; reforming pedagogy by emphasizing learner-centered activities and establishing life-long learning; reforming the curriculum, allowing for the contribution and participation of stakeholders, to meet new challenges and demands of different groups of learners with an emphasis on mathematics, science and technology in parallel with the promotion of pride in national identity and cultural heritage; and reforming resource allocation at the national level on the basis of equity and encouraging local educational authorities and communities to mobilize their resources for education. All involved stakeholders have been urged to join continuing efforts toward the reform (Office of the National Education Commission 1999).

According to the objectives of the educational reform policy, basic education in Thailand is organized in four main levels: Level 1–Grades 1–3 (lower primary), Level 2–Grades 4–6 (upper primary), Level 3–Grades 7–9 (lower secondary), and Level 4–Grades 10–12 (upper secondary). Schooling from Grades 1 to 9 is now compulsory.

Regarding curriculum reform, the ministry of education of Thailand launched a new curriculum, the 2001 Basic Education Curriculum B.E. 2544 (Ministry of Education 2001). Under this new curriculum, for science education, the Institute for the Promotion of Teaching Science and Technology (IPST)—an agency under the direction of the Ministry of Education–plays a major role in reforming science education and, in 2002, established standards for science education in Thailand. The 2002 National Science Curriculum Standards are a broad framework providing curricular strands, learning-standards levels, expected learning outcomes, concept maps of science contents for each grade, a learning process, assessment and evaluation, and examples of lesson plans. The science curricular standard consists of eight strands: living things and living processes; life and the environment; matter and properties of matter; force and motion; energy; changing processes of the earth; astronomy and space; and the nature of science and technology. From Grades 10 to 12, students are divided into science and non-science streams, and science-stream students study physics, chemistry, and biology as advanced science courses offered either as compulsory or elective courses (Institute for the Promotion of Teaching Science and Technology 2002).

There are many differences between the new curriculum and the older one, i.e., the Primary Curriculum (Revision B.E. 2533) (1990) (Ministry of Education 1992). The new curriculum is standards based, consisting of the learning standards that all students in Grades 1–12 must attain. The basic-education schools are responsible for creating their school curricula and covering all contents and learning standards, and these must be suitable for their students and contexts. The differences between the new and old curricula are summarized in Table 1.

According to Table 1, particularly the NOS and astronomy and space sub-strands are unfamiliar for science teachers. The learning standards of this sub-strand are:

Learning Sub-strand 7: Astronomy and Space

Learning Standard SC 7.1

Students must: understand the evolution of the solar system, galaxies, and the universe, and the interrelationships within the solar system and their effects on living things; develop scientific minds and inquiry skills; communicate knowledge learned; and apply knowledge to their everyday lives.

Learning Standard SC 7.2

Students must: understand the importance of space technology to exploring space and natural resources and of applying this to agriculture and communications; develop scientific minds and inquiry skills; communicate knowledge learned; and apply knowledge with morals for both their own lives and the environment.

The new science curriculum, in accordance with the educational reform, requires all Thai science teachers to

Table 1 Summary of curriculum change

Revised Primary Curriculum (1990)	Basic Education Curriculum (2001)
Basic education (12 years) is divided into two main levels: primary (Grades 1–6) and secondary (Grades 7–12)	Basic education is divided into four main levels: Level 1 (Grades 1–3), Level 2 (Grades 4–6), Level 3 (Grades 7–9), and Level 4 (Grades 10–12)
There is a national test administered at the end of each level (2 times)	There is a national test administered at the end of each level (4 times)
Science, social studies, and health education are combined into an "Enhancing Life Experience" unit	Science is distinguished as the "Science Learning Strand"
There are 11 learning units in the Enhancing Life Experience unit	There are eight learning sub-strands in the Science Learning Strand
NOS is not mentioned	NOS is mentioned in Learning Sub-strand 8: Nature of Science and Technology
Astronomy and space included in Learning Unit 8: universe and space	Astronomy and space included in Learning Sub-strand 7: astronomy and space with different content, sequence of content, and learning requirements

embed NOS in their science teaching. However, it does not inform science teachers how to teach NOS. The following section describes the literature regarding teaching NOS.

Teaching NOS

Driver et al. (1996) suggested that NOS should not be regarded as an add-on to science content; rather, it should be tightly linked to the content taught. In addition, a number of NOS research studies (Abd-El-Khalick and Akerson 2004, 2009; Abd-El-Khalick and Lederman 2000; Akerson et al. 2000; Bartholomew et al. 2004; Cakiroglu et al. 2009; Schwartz and Lederman 2002) have suggested that effective teaching of NOS must be conducted in an explicit-reflective manner, i.e., teachers make aspects of NOS an explicit part of classroom discourse and provide learners opportunities to reflect upon and explain their ideas about NOS.

Abd-El-Khalick and Akerson (2009) clarified the meaning of the explicit-reflective framework of teaching NOS: "the label 'explicit' is *curricular* in nature while the label 'reflective' has *instructional* implications (emphases in original) (p. 2163)."

The label "explicit" is intended to emphasize the need for the inclusion of specific NOS learning outcomes in any instructional sequence aimed at developing learners' understanding of NOS. In this case, the comprehension of NOS is a cognitive instructional outcome that should be intentionally targeted and planned for in the same manner as other scientific concepts. Notably, the "explicit" component of the explicit-reflective approach to NOS instruction does not entail a certain pedagogical approach (Abd-El-Khalick and Akerson 2004, 2009).

On the one hand, the "reflective" component does entail instructional elements that need to be incorporated into pedagogical approaches undertaken within the explicit-reflective approach. This element refers to the inclusion of structured opportunities designed to encourage learners to examine their science-learning experiences from within an epistemological framework, which would focus on questions related to the development and validation of, as well as the characteristics of, scientific knowledge. That is, students should have opportunities to analyze their activities from within an NOS framework, map connections between these activities and those of scientists, and make conclusions about scientific epistemology. Simply, an explicit-reflective approach emphasizes student awareness of certain NOS aspects in relation to student learning activities and student reflection on these activities from within a framework comprising these NOS aspects (Abd-El-Khalick and Akerson 2004, 2009).

In addition, Hanuscin et al. (2010) elaborated on four overarching criteria of the explicit approach to teaching NOS: (a) teachers plan to teach a particular aspect of NOS; (b) students are made aware of the target aspect of NOS; (c) students are provided an opportunity to discuss and/or reflect on their ideas about the target aspect of NOS; and (d) teachers elicit students' ideas about NOS before, during, or at the conclusion of the activity.

NOS Embedded in Astronomy and Space

In Thailand, there is generally a lack of learning materials and resources regarding astronomy and space, which is the new learning sub-strand included in the 2001 Basic Education Curriculum. To cope with this problem, in 2002, IPST in cooperation with the Faculty of Science, Chiang Mai University, initiated the teaching and learning of an astronomy and space database. This database can guide Thai teachers and students in teaching and learning about astronomy and space (Soydhurum 2004). However, many problems still existed in Thai astronomy education. In 2009, Pornpan Vitayangkorn, the director of IPST, announced that Thai students' scores in the subject of astronomy and space, according to an international assessment, were lower than average. The main problems were a dispersion of astronomy and space curricula, a lack of learning materials, and teachers' lack of understanding of astronomy and space. Therefore, IPST joined with the Thailand Research Fund (TRF) and the Faculty of Education, Chulalongkorn University, in reforming the astronomy and space curriculum. They planned to create a new astronomy and space curriculum for a nationwide launch in the 2013 academic year (Public Relations Department 2008). Until now, there has not been a section in the Thai science curriculum that explicitly mentions embedding NOS in astronomy and space curricula.

Astronomy and space appears to be one of the topics that can be utilized to articulate several aspects of NOS. In learning about astronomy and space, students are frequently required to build models. Model building is related to NOS, as Matthews (2007, p. 650) stated, "…models are central to scientific practice, and that understanding the epistemological dimension of models is central to philosophy of science, then learning about NOS will involve learning something about the functioning of models in the history of science." By design, according to Taylor et al. (2003), model building in astronomy education potentially promotes students' understanding of NOS in three ways: (a) science is a process that has been constructed by people; (b) science is influenced by the social and cultural framework in which scientists work; and (c) science understanding changes over time.

Research Questions

The research questions guiding the present study are as follows. (a) What are conceptions of NOS held by in-service science teachers at the beginning and end of an NOS workshop and a semester after the workshop? (b) How do science teachers embed their understanding of NOS in teaching astronomy and space?

Methods

This study is a collective case study (Creswell 2007) that was conducted in the first semester of the 2009 academic year. A collective case study addresses the exploration of multiple bounded systems (i.e., science classrooms) over time through detailed, in-depth data collection from multiple data sources.

This study is divided into two phases to answer the research questions mentioned earlier. In the first phase, the NOS workshop was conducted by using an explicit-reflective approach. It includes explicit-reflective NOS activities such as the "tricky tracks", "young or old", and "black box" activities. A detailed description of these activities is elaborated upon elsewhere (Lederman and Abd-El-Khalick 1998). The participants were subsequently asked to analyze the new curriculum, particularly in relation to NOS and astronomy and space, to participate in the model lessons, which integrated NOS into teaching astronomy and space, and to reflect upon their NOS learning experiences. Table 2 presents the summary of learning activities in the NOS workshop.

In the second phase, upon completion of the workshop, each participant was followed-up to explore how he/she embeds NOS into his/her teaching about astronomy and space.

Data Collection

The data were collected from three volunteer primary science teachers. The first case study is *Cathy* (pseudonym). She is a 55 year-old science teacher at School A (pseudonym) located in the central region of Thailand. She graduated with a Bachelor's degree and a major in Thai Language. She is an experienced science teacher with 30 years of teaching experience. *James* (pseudonym) is the second case study. He is 26 years old and has taught science at School A for 2 years. He graduated with a Bachelor's degree in Food Science and Nutrition and earned a 1-year certificate in teaching. The last case study is *Wicky* (pseudonym), a primary science teacher at School B (pseudonym) located in the central region of Thailand. She is 41 years old but has only 10 years of experience teaching science because she was initially not assigned to teach science. Both Schools A and B are small primary schools with less than 500 students.

In the first phase, to explore the participants' conceptions of NOS, the Myths of Science Questionnaire (MOSQ) (Buaraphan 2009b) was employed. The validity and reliability of MOSQ have been reported elsewhere. It was recently employed by Sarkar and Gomes (2010) and found to be highly reliable. MOSQ consists of 14 items addressing four main aspects of NOS, as mentioned in the literature review: (1) scientific knowledge (items 1, 2, 3, 4, 8, and 9); (2) scientific method (items 5, 6, and 7); (3) scientists' work (items 10 and 11); and (4) scientific enterprise (items 12, 13, and 14). All MOSQ items were presented as shown in Table 4 in the "Appendix". The completion of MOSQ took approximately 45 min. To respond to the MOSQ, the respondent was required to select one of three responses (i.e., agree, uncertain, or disagree) that best fits his/her opinion about the statement presented as well as reason to support the selection. Each participant was asked to respond to the MOSQ three times, i.e., at the beginning (pre-test)

Table 2 Learning activities in the NOS workshop

Day	Topic	Learning activity
Day 1	NOS	Tricky tracks, young or old, and black box
		Reflection and discussion
Day 2	Basic Education Curriculum (2001)	Analyze the 2001 Basic Education Curriculum
		Analyze the NOS, astronomy and space learning sub-strands
		Reflect on and discuss how to implement those sub-strands in the classroom
Day 3–5	Model lessons: embedding NOS in teaching about astronomy and space	NOS model lesson on "Sky" based on inquiry approach
		NOS model lesson on "Night and Day" based on problem-solving approach
		NOS model lesson on "Moon Phases" based on learning-cycle approach
		Reflection and discussion

and the end (post-test) of the workshop and a semester after the workshop (delayed-test).

In the second phase, classroom observation, interviews after teaching, and collection of related documents (e.g., lesson plans, handouts, and worksheets) were employed to collect data about how the participants embed NOS in teaching about astronomy and space. The classroom observations were conduced four times for each participant throughout a semester. Each classroom observation took approximately 2 h. The researcher played a role as a non-participant observer and recorded data in field notes. To obtain more complete data, an audiotape recorder was also used in classroom observation. The data recorded on audiotapes were subsequently transcribed verbatim. The interviews after teaching were semi-structured and included this list of questions: How do you feel about your teaching? What are the strengths and weaknesses in your teaching? What do you plan to improve in your future teaching of this topic? Did you embed NOS in your teaching? What aspects of NOS? Why are those aspects of NOS so important for students to learn? How did you embed NOS in your teaching? All interviews were audiotaped and, later, transcribed verbatim. All data from observations, interviews, and documents were included in the data analysis.

Data Analysis

At first, the "agree," "uncertain," or "disagree" responses by a participant were interpreted as informed, uncertain, or uninformed conceptions of NOS, respectively. The supporting reason he or she provided is also brought into consideration before categorization. In addition, the qualitative data derived from classroom observations, interviews after teaching, and collection of documents were analyzed by using a constant comparative method (Glaser and Strauss 1967). The basic stages of this method are: (a) reading throughout data obtained from observations, interviews, and documents and finding out units of meaning, (b) assigning each unit of meaning a code (e.g., 'informed,' 'uncertain,' or 'uninformed' conceptions of NOS, 'implicit' or 'explicit' teaching about NOS), (c) comparing and categorizing the codes; (d) constantly comparing and categorizing new codes emerging from new rounds of analysis, and (e) identifying emerging patterns and relationships. For example, the code "no NOS in lesson plan" obtained from an analysis of documents was compared with existing codes and categories and, eventually, was placed in the 'implicit teaching of NOS' category. The inter-rater reliability of coding (Miles and Huberman 1984) was established in this study by asking three science educators in the field of NOS to independently code the participants' conceptions of NOS (e.g., informed, uncertain, and uninformed conceptions) and teaching NOS (e.g., explicit and implicit teaching). The inter-rater reliability of coding of participants' conceptions of, and teaching about, NOS was established at .94. Any disagreement emerging from this process was resolved in a subsequent meeting.

Results

This study results in two assertions regarding the nature of science teachers' conceptions of NOS and embeddedness of NOS in teaching about astronomy and space.

Assertion 1: Science Teachers' Conceptions of NOS Are Stable and Resistant to Change

Table 3 shows the participants' conceptions of NOS at the beginning and end of the NOS workshop and a semester after the workshop. At the beginning of the workshop, Wicky held more informed conceptions of NOS than James and Cathy. Of 14 items, Wicky, James, and Cathy had informed conceptions of NOS in 11, 8 and 7 items, respectively.

At the end of the workshop, Cathy had developed more informed conceptions of NOS in six of 14 items (items 2, 3, 6, 9, 11 and 12); however, two of these items (items 3 and 11) reverted to being uninformed a semester later. For Cathy, eight conceptions of NOS were placed in the same categories (seven informed and one uninformed) throughout the study. Her most persistently uninformed conception of NOS was regarding the accumulation of scientific knowledge (item 8), which related to "Baconian induction" (McComas 1998, p. 58), i.e., the "accumulation of evidence makes scientific knowledge more stable."

James changed his uninformed conceptions to being informed in only one of 14 items (item 9); however, this informed conception reverted to being uninformed after a semester of teaching in school. He had 11 conceptions in the same categories (eight informed and three uninformed) throughout the study. The three most difficult conceptions of NOS for James were regarding theories and laws, accumulation of scientific knowledge, and theory-laden observation (items 3, 8, and 11).

Similar to James, Wicky developed a more informed conception of NOS in only one of 14 items (item 12). After a semester of teaching in school, Wicky's existing informed conception of NOS became uninformed (item 3). Twelve conceptions of NOS held by Wicky were placed in the same categories (10 informed and two uninformed) throughout the study. The two most difficult conceptions of NOS for Wicky were regarding the accumulation of scientific knowledge and theory-laden observation (items 8 and 11).

The NOS workshop, to some extent, helped the participants develop an understanding of NOS, especially in increasing an ability to provide detailed reasons or

Table 3 Conceptual development of NOS

Item	Participant	Conception of NOS		
		Pre	Post	Delayed
1. Hypotheses are developed to become theories only	Cathy	*Informed* Hypotheses are not always true	*Informed* Hypotheses are scientists' guesses that are useful in developing scientific knowledge	*Informed* In the case that hypotheses are true, they are developed to become theories
	James	*Informed* If hypotheses are rejected by experiments, they never become theories	*Informed* Some hypotheses cannot be developed to become theories	*Informed* Hypotheses are scientists' guesses, so they are not always true. In this case, they never become theories
	Wicky	*Informed* Some hypotheses are not true and are then discarded	*Informed* Some hypotheses lack supporting evidence to confirm they are true	*Informed* Some hypotheses are not reasonable enough
2. Scientific theories are less secure than laws	Cathy	*Uninformed* Scientific laws are more secure than theories because they are repeatedly tested and found true in all cases	*Informed* Both theories and laws are valuable products of science	*Uninformed* I agree
	James	*Uncertain* I am not sure	*Uncertain* I am not sure	*Informed* If scientific theories are reasonable enough, they can substitute laws
	Wicky	*Informed* I disagree	*Informed* Scientific theories and laws are equal in terms of scientific knowledge	*Informed* I disagree
3. Scientific theories can be developed to become laws	Cathy	*Uninformed* I agree.	*Informed* Scientific theories explain laws.	*Uninformed* I agree.
	James	*Uninformed* I agree	*Uninformed* I agree	*Uninformed* I agree
	Wicky	*Informed* I disagree	*Informed* Scientific theories explain patterns in nature, as stated in laws	*Uninformed* If theories are acceptable and reasonable, they can be developed to become laws
4. Scientific knowledge cannot be changed	Cathy	*Informed* New discoveries are occurring all the time, so scientific knowledge can be changed	*Informed* Presently, many modern tools are emerging. Such tools provide us more exact, detailed data that are useful in explaining and expanding our existing knowledge	*Informed* Scientific knowledge can be changed with the discovery of opposing evidence
	James	*Informed* Scientific knowledge can be changed. For example, we previously believed that the world is flat. With modern tools, however, we realize that the world is not flat	*Informed* Scientific knowledge can be changed. People used to believe that the world is flat. However, pictures taken by satellites show that the world is round	*Informed* I disagree
	Wicky	*Informed* Scientific knowledge can be changed because of technology. Technology brings more elaborated data that lead us closer to reality, more and more	*Informed* Scientific knowledge can be changed with opposing evidence	*Informed* Scientific knowledge can be changed with the discovery of more reasonable data

Table 3 continued

Item	Participant	Conception of NOS		
		Pre	Post	Delayed
5. The scientific method is a fixed step-by-step process	Cathy	*Informed* The scientific method is not fixed but depends on situation.	*Informed* The scientific method is not fixed because some steps can be skipped. This depends on individual scientists.	*Informed* The steps in seeking scientific knowledge can be adjusted to suit the topic of investigation.
	James	*Informed* Some steps can be skipped or added to suit the experiment	*Informed* Some steps of the scientific method may be removed or added to suit the nature of investigation	*Informed* I disagree
	Wicky	*Informed* The steps for doing science are not sequenced as 1–2–3–4–5. Scientists can start from the second or third step and then return to the first step	*Informed* Some steps of the scientific method can be alternated. For example, we can set a new hypothesis while doing experiment	*Informed* The scientific method is not fixed but depends on time and situation
6. Science and the scientific method can answer all questions	Cathy	*Uninformed* If we follow the right steps of the scientific method, we can answer all questions	*Informed* Some things in the world cannot be explained by the scientific method, e.g., supernatural phenomena	*Informed* Some beliefs or questions cannot be explained or answered by the scientific method
	James	*Informed* The scientific method cannot explain some mysteries	*Informed* Science cannot clearly explain ghosts and spirits	*Informed* I disagree
	Wicky	*Informed* There are some phenomena that science cannot explain. Scientists oftentimes rely on their direct experiences	*Informed* Some things in the world cannot be explained or answered by science, e.g., supernatural phenomena	*Informed* Science cannot explain some difficult topics
7. Scientific knowledge comes from experiments only	Cathy	*Informed* There are many ways to develop scientific knowledge	*Informed* Conducting an experiment is not the only method for developing scientific knowledge. The other methods are observation and survey, which can be applied suitably in individual situations	*Informed* Scientific knowledge can come from collecting documents or observation
	James	*Informed* Observation can be used to develop scientific knowledge	*Informed* Scientific knowledge can come from everyday experience	*Informed* I agree
	Wicky	*Informed* Sometimes, scientific knowledge is accidentally discovered or built from story telling	*Informed* Some scientists discovered scientific knowledge by accident. The important thing is that scientists' awareness of the meanings embedded in the phenomena under study that requires knowledge, creativity, and imagination	*Informed* The imaginations of scientists can lead to scientific knowledge
8. Accumulation of evidence makes scientific knowledge more stable	Cathy	*Uninformed* Accumulating evidence leads to more firm scientific knowledge	*Uninformed* When scientists find more evidence, scientific knowledge they have built becomes more credible	*Uninformed* Strong scientific knowledge needs lots of supporting evidence
	James	*Uninformed* I agree	*Uninformed* I agree	*Uninformed* I agree

Table 3 continued

Item	Participant	Conception of NOS		
		Pre	Post	Delayed
	Wicky	*Uninformed*	*Uninformed*	*Uninformed*
		I agree	The credibility of scientific knowledge is directly related to the quantity of supporting evidence	I agree
9. A scientific model (e.g., the atomic model) expresses a copy of reality	Cathy	*Uncertain*	*Informed*	*Informed*
		I am not sure	Scientific models are created from credible evidence or scientists' imaginations. Such models cannot access reality	Scientific models are constructed from the imagination. Scientists try to construct models that are as close to the reality as possible
	James	*Uninformed*	*Informed*	*Uninformed*
		I agree	The atomic models are created by scientists and supposed to represent structure and behaviors of atoms	I agree
	Wicky	*Informed*	*Informed*	*Informed*
		The atomic models represent atoms as they are supposed to be. In reality, atoms may not be like the models	Scientific models represent scientists' ideas at a certain period in time. Some models lack clear supporting evidence and can be changed with the discovery of new evidence	Scientific models depend on knowledge at a certain period in time
10. Scientists do not use creativity and imagination in developing scientific knowledge	Cathy	*Informed*	*Informed*	*Informed*
		Imagination stimulates scientists' eagerness and inquiries	Imagination and creativity challenge and stimulate the eagerness of scientists and their investigations	Imagination creates scientists' creativity and challenges them to seek more knowledge
	James	*Informed*	*Informed*	*Informed*
		Success in developing scientific knowledge requires scientists' creativity and imagination	Scientists use their creativity and imagination before doing experiments or starting investigations	I disagree
	Wicky	*Informed*	*Informed*	*Informed*
		Most new ideas are developed from human creativity and imagination	The development of scientific knowledge relies on creativity and imagination	I disagree
11. Scientists are open-minded without any biases	Cathy	*Uninformed*	*Informed*	*Uninformed*
		Scientists always rely on evidence	It is individual. Some scientists have biases and distort data	Scientists do not bring their feelings into decision making but instead rely on reasonable data
	James	*Uninformed*	*Uninformed*	*Uninformed*
		I agree	I agree	I agree
	Wicky	*Uninformed*	*Uninformed*	*Uninformed*
		I agree	Scientists must be responsible and accept the results of experiments. Power is not involved in scientists' work	I agree
12. Science and technology are identical	Cathy	*Uncertain*	*Informed*	*Informed*
		Scientists discover theories and laws and use them to develop tools or technology	Science is conducted for the sake of knowledge. Technology is originated from scientific knowledge and conducted for the sake of comfortable lives	Technology is a helping tool for scientists to do their investigations more comfortably
	James	*Uninformed*	*Uncertain*	*Uninformed*
		I agree	I am not sure	I agree

Table 3 continued

Item	Participant	Conception of NOS		
		Pre	Post	Delayed
	Wicky	*Uninformed*	*Informed*	*Informed*
		I agree	Science emphasizes seeking more knowledge; technology emphasizes applying scientific knowledge for lives and business	Science deals with knowledge. Technology deals with economy and comfort
13. Scientific enterprise is an individual enterprise	Cathy	*Informed*	*Informed*	*Informed*
		Cooperation among scientists leads to correct and clear scientific knowledge	Doing scientific enterprise requires teamwork	Cooperation and discussion among scientists leads to a clear, unique scientific conclusion
	James	*Informed*	*Informed*	*Informed*
		Some scientific enterprises can be supported by group work	Group work is one strategy in doing science	I agree
	Wicky	*Informed*	*Informed*	*Informed*
		Science can be conducted individually or cooperatively	Doing science requires cooperation of people from diverse areas of expertise and disciplines	I disagree
14. Society, politics, and culture do not affect the development of scientific knowledge	Cathy	*Informed*	*Informed*	*Informed*
		Some cultures make scientists resist some modern ideas	Some deep-rooted cultures, traditions, and beliefs make people resist modern ides and new discovery	I disagree
	James	*Informed*	*Informed*	*Informed*
		In a country at war, it is very hard to develop science	In a society at war, science is slowly developed	I disagree
	Wicky	*Informed*	*Informed*	*Informed*
		The major aim of country at war is to develop weapons, whereas, the developed country aims to develop technology	Some scientific investigations, such as cloning, bring society into debate	I disagree

Directions: Please select the choice that best reflects your opinion and provide an explanation supporting your selection

examples to support their chosen responses. The participants' conceptions of NOS were stable because they did not show any remarkable shifts in the conceptions of NOS. In addition, the participants' conceptions of NOS were resistant to change. In the cases of Cathy and James, for example, their informed conceptions of NOS reverted to being uninformed a semester after the workshop. The most common uninformed conception of NOS for all participants was regarding the belief of Baconian induction.

Assertion 2: Science Teachers' Understanding of NOS Is Not Directly Related to Their Classroom Practices

Cathy did not mention NOS in her lesson plans. Cathy's classroom consists of 37 Grade 6 students (13 male, 24 female). In teaching about solar eclipses, she began the lesson by asking her students: "What are the characteristics of a solar eclipse? How does it occur?" Cathy extensively used models in teaching about solar eclipses. For example, Cathy used an orange and a lemon to represent the sun and the moon, respectively. She used a torch to illuminate the lemon to create a shadow on the orange to show her students how a solar eclipse occurs. Later, the students were placed in groups of four and given those materials to model and study a solar eclipse. Cathy also employed a poster of a solar eclipse to help the students understand the targeted concepts. She emphasized to the students that both the distances and planes of the Sun, Moon, and Earth are crucial to solar-eclipse phenomena. Cathy made the students aware of two limitations of models of the solar system: "The scale of models does not accurately represent an authentic scale of phenomena;" and "Models are not real." She did not further provide the students with an opportunity to reflect upon and discuss NOS.

Another example of using a model to teach astronomy and space is given by the lesson on moon phases. Cathy employed the activity she learned from the NOS workshop to teach her students. The classroom was modified to be a darkroom, and the students were given a table-tennis ball, a ruler, and a torch to model and study, with the teacher's guidance, how moon phases occur. However, Cathy did not mention the nature of scientific models. Interestingly, Cathy employed a story about a lunar eclipse. She told the students the traditional Thai tale of a monster named "Rahoo" (in Thai) who keeps the moon in his mouth, which causes the lunar eclipse. However, at the conclusion of the lesson, she did not emphasize the difference between the explanation of the lunar eclipse derived from the tale and from science.

James did not write a lesson plan on astronomy and space embedded with NOS. His classroom consisted of 36 Grade 1 students (25 male, 11 female). James began the lesson on the direction and the rising and falling of the Sun by asking the students to make groups of four and move to the school field. The next dialogue illustrated James' questions and students' answers:

James:	What is the direction from which the Sun always rises?
Students:	(Point to the East)
James:	OK. Turn your right side towards this direction (the East)
James:	So that now where is the East?
Students:	My right
James:	And where is the West?
Students:	Left
James:	Where is the North?
Students:	Front
James:	Where is the South?
Students:	Back
James:	So, you have to turn which part of your body to the East?
Students:	Right part
James:	If you are lost in the forest, and your home is North, which way will you walk?
Students:	Front
James:	OK. Let's go back to our classroom and do the assignment in your textbook

After that, the students completed a worksheet, drew pictures showing the relationship between the directions and the Sun and, finally, wrote a mind map. In this lesson, James strongly emphasized questioning and relied on a textbook.

James never mentioned NOS in his teaching, though the lesson he taught was related to observation as a way to produce evidence. James paid more attention to classroom control because there were many more male students in his classroom than females. He also had little experience in teaching grade 1 students, as he reflected:

> My Grade 1 students are very naughty. I have to catch up with them all the time. It's my first year of teaching in Grade 1. Formerly, I taught Grades 3 and 4 for many years.

Similar to Cathy and James, Wicky did not include NOS in her lesson plans. Wicky was responsible for teaching 33 Grade 4 students (18 male, 15 female). In teaching about the solar system, she extensively employed posters and models. She began the lesson by requiring students to make groups of four and draw pictures of the solar system. After that, she required students from each group to present their drawings of the solar system to the class. After the student presentations were finished, Wicky distributed the teacher's notes on the solar system to all students and required them to study and draw a correct model of the solar system. The students were also asked to present what they learned about the solar system to the class. An example of the dialogue between Wicky and her students is the following:

Wicky:	What do you learn about?
Students:	The solar system
Wicky:	What planet is placed at the center of the solar system?
Students:	The Sun
Wicky:	How many planets orbit around the sun?
Students:	Eight planets
Wicky:	Can you tell me the name of those eight planets
Students:	…(They state the names of eight planets by reading from the teacher's notes)

Subsequently, Wicky presented a poster of the solar system to the class and explained it. She required the students to build a model of the solar system from clay, toothpicks, and a plastic base after students had studied the teacher's notes. Although Wicky wandered around the classroom during the model-building activity, she did not advise the students much. The students were left on their own to build models. Subsequently, Wicky required three groups as a class representative to present their models of the solar system to the class. However, she did not notice that one group of students created a ring for the Earth in the solar system. Regarding this lesson, Wicky missed an opportunity to address two important aspects of NOS. First, she did not emphasize the tentative nature of scientific knowledge in the case of Pluto. That is, there are eight planets in the solar system now, not nine planets as in the past. Second, the model of the solar system is aimed at representing its structure, not an exact replica.

The assumption that science teachers' understanding of NOS is directly related to their classroom practice is not supported by this study. With different degrees of understanding of NOS, all participants taught NOS implicitly.

Comparing Wicky and Cathy, who had the highest and lowest degrees of understanding of NOS, respectively, Cathy surprisingly showed more intention to explicitly teach NOS than Wicky. All participants were unaware of and missed most of their opportunities to address aspects of NOS embedded in the astronomy and space topics they taught.

Discussion

This study shows that an explicit-reflective NOS workshop, specifically in the context of astronomy and space, is beneficial for promoting science teachers' conceptions of NOS to some extent (Akerson et al. 2000, 2007; Buaraphan 2011; Khishfe and Lederman 2007; Schwartz et al. 2004). To strengthen the NOS workshop, Khishfe and Lederman (2007) suggest that real-life, controversial, social-science-based issues, such as global warming, should be selected as a context for illustrating NOS aspects.

This study shows that science teachers' conceptions of NOS are stable and resistant to change. The persistence of NOS conceptions is presented in many studies (Akerson et al. 2007; Lederman 1999). The short instructional period employed in an NOS intervention is insufficient to change science teachers' firm conceptions of NOS (Cakiroglu et al. 2009). In addition, some developed conceptions of NOS held by the participating science teachers were forgotten when they returned to their classrooms, as found by Akerson et al. (2009b).

Model building to learn about astronomy and space can be linked with many aspects of NOS. Taylor et al. (2003) stated that there are three key aspects of NOS in astronomy education: science is a process that has been constructed by people; science is influenced by scientists' social and cultural frameworks; and science understanding changes over time. In addition, Akerson et al. (2009b) illustrated many aspects of NOS in scientific models: scientific models illustrate the distinction between observation and inference; scientific models show how scientists create (creative NOS); scientific models are created from data (empirical NOS); and scientific models can be changed (tentative NOS). Science teachers in this study frequently used models for teaching astronomy and space-related topics; however, they did not reveal key aspects of NOS in building models. Additionally, they did not employ models as assessment tools, as found in Akerson et al. (2009b).

Science teachers in this study did not use historical examples to teach about NOS, although there are many examples available in astronomy. From 80 historical vignettes collected by McComas (2008), 17 of them (22%) come from the field of astronomy. These vignettes are useful in helping communicate certain key aspects of NOS and, in turn, providing students with both an engaging and accurate view of the underlying NOS.

Based on the four overarching criteria of the explicit-reflective approach in teaching about NOS, as proposed by Hanuscin et al. (2010), science teachers in this study teach NOS implicitly. That is, they did not plan to teach NOS (Akerson et al. 2009b), make students aware of the NOS, provide students an opportunity to reflect on NOS, or elicit students' ideas about NOS throughout instruction. Teaching about NOS appeared to be a difficult task for the science teachers in this study, as also found in Hanuscin et al. (2010). NOS appeared to be a new learning sub-strand for the science teachers in this study, and the new science curriculum does not make any suggestions for how to embed NOS in teaching. Moreover, the science teachers have to teach astronomy and space-related topics, which is an unfamiliar learning sub-strand for them. Therefore, embedding NOS in teaching about unfamiliar content, as is the case in this study, is more difficult and requires a great amount of support. As Henze et al. (2008) found, limited subject matter knowledge (in this case, knowledge of NOS) and a positivist view of models and modeling negatively impacts science teachers' development of pedagogical content knowledge (PCK) (Shulman 1986).

As in a number of NOS studies (Akerson et al. 2009a; Lederman 1999; Lederman and Zeidler 1987; Mellado et al. 2007; Trumbull et al. 2006; Waters-Adams 2006), this study supports the proposition that science teachers' conceptions of NOS are not directly related to their classroom practices. With different degrees of understanding of NOS, all participants teach NOS implicitly. Knowledge of NOS is a necessary but insufficient condition for teaching about NOS (Abd-El-Khalick et al. 1998; Abd-El-Khalick and Lederman 2000; Bartholomew et al. 2004). Akerson and Abd-El-Khalick (2003) stated that a science teacher needs support to translate his or her NOS views and intentions into pedagogically appropriate instructional activities that would make the target NOS aspects accessible to students. In the Thai context, such support does not exist at all. Furthermore, before any support is provided to science teachers, they themselves need to be aware of the importance of NOS as a necessary aspect of curriculum to be taught. Science teachers must devote time to NOS instruction (Khishfe and Lederman 2007). In addition, science teachers must intend and believe that they can teach NOS and believe that their students can learn NOS. Lederman (1999) and Schwartz and Lederman (2002) argued that internalizing the importance of NOS as a significant instructional outcome plays a major role in teachers' willingness to teach NOS.

NOS has been explicitly and formally included in the national science curriculum in Thailand since 2001. However, for a decade, science teachers in Thailand have continued to teach NOS merely implicitly. There are several potential explanations for this circumstance.

First, a decade ago, there was a lack of documents and research regarding how to embed NOS in teaching science in each grade level. Science teachers were left with a new national science curriculum, which includes one learning standard of NOS, as stated earlier. Subsequently, science teachers have had to discover their own methods for embedding NOS in their teaching. Moreover, many studies (Buaraphan 2009a, b) conducted in Thailand show that science teachers themselves lack an understanding of NOS.

Second, Thailand has undergone substantial educational reform, with a major driver being the Asian economic crisis that occurred in the late 1990s. The educational reform yielded a change from the former science curriculum to a standards-based science curriculum that is intended to be learner-centered in nature. However, Thailand, unlike some western countries, did not change the assessment regime to make it consistent with the new learner-centered curriculum. It retains a series of external summative examinations that act as gatekeepers to further study, including university participation (Coll et al. 2010). Although NOS appears as one of the learning sub-strands in the Thai science curriculum, its content has not been included in any format in the university entrance examination. Moreover, the NOS learning standard is only the one that remains without explicit, proper assessment in classrooms. The importance of NOS is, therefore, neglected in the Thai classroom context. As Coll et al. (2010, pp. 18–19) state: "…if we fail to make commensurate modifications to the assessment regime, then teachers will likely teach in much the same way they always did, because they will be judged by the outcomes; such as pass rates in external summative examinations."

Third, teaching, or even learning, about NOS is a novel experience for science teachers in Thailand. Most science teachers have had first-hand experience with traditional science content knowledge but lack experience with and knowledge of NOS (McComas 2008). First, they need an adequate, informed understanding of NOS. In addition, they need direct experience with both learning and teaching NOS. The professional development programs for learning and teaching NOS are urgently needed.

The next step to help science teachers teach about NOS is to provide them with a knowledge base for teaching NOS. Science teachers need PCK for teaching about NOS. The lack of PCK can act as an obstacle to the transfer of teachers' NOS beliefs into their classrooms (Mellado et al. 2007). Schwartz and Lederman (2002) proposed three knowledge components of PCK for NOS, i.e., knowledge of NOS, knowledge of the science subject matter, and knowledge of pedagogy. Science teachers must blend these three knowledge components together to create a PCK for NOS. However, simply providing science teachers with a packet of activities will not suffice to enhance their PCK for NOS. Science teachers need to find their own methods to best embed NOS in their teaching, not merely imitate the activities of others. Meaningful professional development relative to NOS instruction should empower teachers to develop their own instructional methods and materials (Schwartz and Lederman 2002). Teachers need help to develop sets of activities applicable to their classrooms and that have a sense of authenticity and ownership (Bartholomew et al. 2004).

To successfully teach NOS, science teachers need support from science-teacher educators through helping them translate their NOS comprehension into appropriate learning activities, to make NOS accessible to their students (Akerson and Abd-El-Khalick 2003). Classroom support, such as on-site visits with ongoing feedback for individual teachers (Posnanski 2010), is needed to help them address their understanding of NOS, awareness and attention to teach NOS, instructional strategies for NOS, and development of pedagogical skills for their classrooms (Bartholomew et al. 2004).

Implications

Many science teachers possess uninformed conceptions of NOS. Without proper intervention, such erroneous conceptions can be perpetuated and are passed on to a new generation of students (Akerson et al. 2007). Helping science teachers develop more informed conceptions of NOS is now a primary task for science-teacher educators. Based on empirical evidence (Akindehin 1988; Billeh and Hassan 1975; Carey and Strauss 1968; King 1991; Ogunniyi 1982), explicit-reflective instruction about NOS, as employed in the NOS workshop in this study, has the potential to improve science teachers' conceptions of NOS.

Simply including NOS in the science curriculum does not guarantee that science teachers will teach NOS, as has been found in the Thai context. First, science teachers must perceive NOS as "must-teach" content, not merely as a byproduct of the inquiry process. They must also intend to teach NOS explicitly and believe that their students must and can learn NOS. Cultivation of science teachers' awareness of the importance of NOS, intention to teach NOS, and devoting time to teach NOS have appeared as the second task for science-teacher educators.

A need in the Thai science education context that emerged from this study is the establishment of a policy to promote science teachers to explicitly, reflectively teach about NOS. From Fensham's (2009) intensive discussion about policy and practice in science education, it is the responsibility of researchers to critique and establish policy for improving the practice of science education. Policy, research, and practice must be considered as being related to each other. The positive example of policy to practice with respect to general educational policy in Thailand raised by

Fensham (2009) is the requirement that high-school students in the "science stream" study physics, chemistry, and biology for 3 years. This is one policy decision in Thailand that has had a remarkably direct effect on student learning of the sciences. To be more successful with NOS teaching and learning, an educational policy aimed at promoting teaching and learning about NOS is urgently needed, especially in the science education context in Thailand.

Importantly, to teach NOS effectively, a science teacher needs PCK for NOS, which does not come from his or her imitation of other teachers' teaching strategies on NOS. Rather, PCK for NOS must be constructed on the basis of an individual science teacher, which is suitable for his or her individual classroom. Developing a sense of authenticity and ownership is needed in developing science teachers' PCK for NOS. The sense of authenticity derives from the science teacher's NOS instructional activities that work in their own classrooms. The sense of ownership derives from the science teacher's NOS instructional activities, which are built upon their own pedagogical knowledge and skills.

Limitations of the Study

This intention of this study is not to generalize the findings to a larger population of in-service science teachers in Thailand. A small sample employed as a collective case study is beneficial for collecting more in-depth data. Although this study has a limitation in its generalization, the transferability of the findings of this study can be established by considering the similarity of the context of this study with the readers' contexts.

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Appendix

See Table 4.

Table 4 The Myths of Science Questionnaire (MOSQ)

Statement	Opinion
1. Hypotheses are developed to become theories only	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
2. Scientific theories are less secure than laws	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
3. Scientific theories can be developed to become laws	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
4. Scientific knowledge cannot be changed	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
5. The scientific method is a fixed step-by-step process	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
6. Science and the scientific method can answer all questions	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
7. Scientific knowledge comes from experiments only	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
8. Accumulation of evidence makes scientific knowledge more stable	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
9. A scientific model (e.g., the atomic model) expresses a copy of reality	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
10. Scientists do not use creativity and imagination in developing scientific knowledge	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
11. Scientists are open-minded without any biases	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
12. Science and technology are identical	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
13. Scientific enterprise is an individual enterprise	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
14. Society, politics, and culture do not affect the development of scientific knowledge	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..

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