

Thai In-service Science Teachers' Conceptions of the Nature of Science

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Understanding of the Nature of Science (NOS) serves as one of the desirable characteristics of science teachers. The current study attempted to explore 101 Thai in-service science teachers' conceptions of the NOS, particularly scientific knowledge, the scientific method, scientists' work, and scientific enterprise, by using the Myths of Science Questionnaire (MOSQ). The results revealed four characteristics of the teachers' conceptions of the NOS: High Informed with High Confidence (HIHC); High Informed with Low Confidence (HILC); Low Informed with High Confidence (LIHC); and Low Informed with Low Confidence (LILC). Many teachers in particular those in the LIHC group, who had uninformed conceptions but highly believed they were correct, need urgent help in modifying their conceptions of the NOS regarding scientific theories and laws, science as cumulative knowledge, theory-laden observation, and subjectivity in science. The implications related to the utilisation and revision of the MOSQ and science teacher professional development programmes are also discussed.

Key words: In-service Science teacher; Nature of Science; Myths of Science Questionnaire; Thailand

Introduction

Science is an important subject for all levels of education. However, research studies have shown that many students, and even some teachers, possess an inadequate understanding of science and its nature. This situation might be harmful, "particularly in societies where citizens have a voice in science funding decisions, evaluating policy matters and weighing scientific evidence provided in legal proceedings. At the foundation of many illogical decisions and unreasonable positions are misunderstandings of the character of science" (McComas, Almazroa, & Clough, 1998, p. 511). An understanding

of the nature of science (NOS) has been established as one of the desirable characteristics of a scientifically literate person, who, in general, “should develop an understanding of the concepts, principles, theories, and processes of science, and an awareness of the complex relationships between science, technology, and society ... (and) more important(ly) ... an understanding of the nature of science” (Abd-El-Khalick & BouJaoude, 1997, p. 673).

Many science curricula now aim to help learners attain an adequate understanding of the NOS, which is an important component of scientific literacy (American Association for the Advancement of Science [AAAS], 1993). There are various advantages for the inclusion of the NOS in the science curricula. Driver, Leach, Miller, and Scott (1996) have suggested five arguments supporting the inclusion of the NOS as a goal of science instruction that the NOS enhances learning of science content, understanding of science, interest in science, decision making in science-related issues, and science instructional delivery.

The proclamation of the National Education Act B.E. 2542 (1999), being revised in B.E. 2545 (Office of the Education Council, 2002), in Thailand brings all stakeholders together in joint continuing efforts toward education reform. Science is emphasised and situated in section 23 of the National Education Act (2002):

*“Education through formal, non-formal, and informal approaches shall give emphases to knowledge, morality, learning process, and investigation ... **scientific and technological knowledge and skills**, as well as knowledge, understanding and experience in management, conservation, and utilisation of natural resources and the environment in a balanced and sustainable manner...”*
(Office of the Education Council, 2002, p. 10)

To support the reform, the Ministry of Education launched a new curriculum, the Basic Education Curriculum (Ministry of Education, 2001), which consists of eight Learning Strands. In the Science Learning Strand, the NOS is explicitly emphasised in Learning Sub-strand 8: The Nature of Science and Technology, which consists of one standard (Standard Sc 8.1):

*“The student should be able to **use** the scientific process and scientific mind in investigation, **solve** problems, **know** that most natural phenomena have a definite period of investigation, (and) **understand** that science, technology and environment are interrelated (Institute for the Promotion of Teaching Science and Technology, 2002, p. 7).”*

Teachers must have an understanding of what they are attempting to communicate to their students (Lederman, 1992), as they cannot possibly teach what they do not understand. Consequently, without sufficient internalising of informed views of the NOS, science teachers cannot effectively address the NOS in the classroom (Abd-El-Khalick & Lederman, 2000). An adequate understanding of the NOS allows science teachers to model appropriate science-related behaviours and attitudes (Murcia & Schibeci, 1999) that strongly influence students' views of the NOS (Palmquist & Finley, 1997). As Lederman (1992) pointed out, 'the most important variables that influence students' beliefs about the NOS are those specific instructional behaviours, activities, and decisions implemented within the context of a lesson' (p. 351). For example, in the case of language, the way teachers verbally present scientific enterprise has an impact on the way students formulate their views about science (Munby, 1967; Zeidler & Lederman, 1989). Hence, promoting teachers' understanding of the NOS is clearly a prerequisite for effective science teaching (McComas, Clough, & Almazroa, 1998). However, many studies reveal that most science teachers possess an inadequate, incoherent, and fluid understanding of the NOS (Abd-El-Khalick & BouJaoude, 1997; Lederman, 1992).

The Nature of Science

Although the NOS is neither universal nor stable, it is generally agreed that it encompasses various fields, especially epistemology, which involve how scientific knowledge is generated and the character of science (Lederman, 1992). McComas, Clough, and Almazroa (1998) provide a good overall description of the NOS:

"The nature of science 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 endeavours."
(p. 4)

From an analysis of eight international science standard documents, those authors (McComas, Clough, & Almazroa, 1998) summarised a consensus view of the NOS. Some aspects of the NOS are that scientific knowledge is tentative; scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments, and scepticism; there is no

universal step-by-step scientific method; laws and theories serve different roles in science; observations are theory-laden; scientists are creative; science and technology impact on each other; and scientific ideas are affected by their social and historical milieu (McComas, Clough, & Almazroa, 1998, pp. 6-7).

In-service Science Teachers' Conceptions of the Nature of Science

With the use of different methods and instruments, the literature suggests that most in-service science teachers possess an inadequate understanding of the NOS. Their conceptions of the NOS are mixed, fluid, and incoherent (Abd-El-Khalick & Boujaoude, 1997; Dogan & Abd-El-Khalick, 2008; Haidar, 1999). Also, there is no significant relationship between science teachers' academic background or personal antecedents in school and their conceptions of the NOS (Carey & Stauss, 1970; Lederman, 1992; Mellado, 1997). The studies related to conceptions of the NOS held by science teachers can be categorised in four major groups: scientific knowledge, scientific method, scientists' work, and scientific enterprise.

Scientific Knowledge: Hypotheses, Theories, and Laws

In various studies, a majority of science teachers had naïve conception regarding a hierarchical relationship between hypotheses, theories, and laws (Abd-El-Khalick & Boujaoude, 1997; Dogan & Abd-El-Khalick, 2008; Haidar, 1999; Rubba & Harkness, 1993). They believed that when a hypothesis is proven correct, it becomes a theory. After a theory has been proved true many times by enough evidence or different people, and has been around for a long time, it becomes a law. Accordingly, scientific theories were a lesser type of knowledge than laws (Akerson, Morrison, & McDuffie, 2006; Akerson & Donnelly, 2008). The availability or accumulation of supporting evidence was also linked with the status of the truth or correctness of hypotheses, theories, and laws (Dogan & Abd-El-Khalick, 2008). The conception that these constructs are different types of ideas was not grasped (Abd-El-Khalick & Boujaoude, 1997). In addition, 29.6% of in-service science teachers confused a scientific theory with a scientific fact. They believed that theories were facts before being proven by experiment (Tairab, 2001, p. 246).

Scientific Knowledge: Tentativeness of Science

Regarding the status of scientific knowledge, in-service science teachers can be categorised into two groups using a static-dynamic split. The science teachers in the first group view science as stable or having a static status, while those in the second group view science as tentative or having a dynamic status. In the static-science group, for example, 24.1% of science teachers claimed that science is a collection of facts or a body of knowledge that explains the world (Tairab, 2001). Scientific knowledge, therefore, was regarded as static (Behnke, 1961). The major purpose of scientific research is, therefore, to collect as much data as possible (Craven, Hand, & Prain, 2002; Tairab, 2001). In the dynamic-science group, the science teachers generally believed in the tentativeness of scientific knowledge (Dogan & Abd-El-Khalick, 2008). For example, four of five primary teachers in Lunn's study (2002) believed that science is constantly evolving to adequately give a full world-view, especially some mysterious patterns in nature. Theories, for example, can be renewed and changed both in the light of new knowledge and new facts.

Scientific Knowledge: Cumulative Knowledge

Scientific knowledge as cumulative knowledge was the naïve conception being linked to their status of truth or correctness (Dogan & Abd-El-Khalick, 2008). Most in-service science teachers strongly believed that scientific knowledge is cumulative (Akerson & Donnelly, 2008; Ma, 2008). The advancement of science, therefore, depends heavily on the accumulation of facts or increasing observation rather than changes in theory (Brickhouse, 1990; Haidar, 1999).

Scientific Knowledge: Scientific Model

'Scientific models are copies of reality' is a popular uninformed conception of the NOS for most science teachers (Dogan & Abd-El-Khalick, 2008). Scientific models, in their view, are copies of reality rather than human inventions (Abd-El-Khalick & BouJaoude, 1997) because scientists say they are true or because much scientific observations and/or research have shown them to be true (Dogan & Abd-El-Khalick, 2008). However, many teachers, especially those who hold constructivist views, can articulate the role of scientific models as scientists' best ideas or educated guesses to represent reality rather than exact replicas of experienced phenomena (Haidar, 1999).

Scientific Method: Universal, Step-wise Method

The scientific method is commonly perceived by science teachers as a universal step-wise method (Abd-El-Khalick & BouJaoude, 1997; Dogan & Abd-El-Khalick, 2008; Haidar, 1999). This can be attributed to the science curriculum that presents the scientific method as a sequence of steps that all students have to followed exactly in order to reach certain results (Haidar, 1999) or unambiguous scientific truth (Brickhouse, 1990). For a majority of science teachers, good scientists were, therefore, those who follow a recipe – the steps of the scientific method – in their investigations (Abd-El-Khalick & BouJaoude, 1997; Haidar, 1999).

Scientists' Work: Theory-laden Observation and Subjectivity

Some of the most common bipolar views of the NOS are subjectivity and objectivity, theory-laden and theory-free, or value-laden and value-free. For most science teachers, subjectivity plays a major role in the development of scientific ideas (Abd-El-Khalick & BouJaoude, 1997) because scientists' worldviews or paradigms can affect their scientific thinking and decision-making (Lunn, 2002, p. 664). However, many science teachers strongly believed in objectivity in science, which is firmly based upon theory-free or value-free observation. For example, nearly half of science teachers held the naïve conception that observation is not influenced by the theories that scientists hold (Brickhouse, 1990; Dogan & Abd-El-Khalick, 2008; Haidar, 1999). Most science teachers (71%) adopted the idealistic view that the scientists' interpretation was objective and far from their frames of reference (Abd-El-Khalick & BouJaoude, 1997; Rampal, 1992).

Scientists' Work: Creativity and Imagination in Science

The role of creativity and imagination in the construction of scientific ideas is overlooked by most science teachers because they believe that scientists must follow a fixed-step scientific method (Abd-El-Khalick & BouJaoude, 1997). For example, there were less than 10% of science teachers in Rampal (1992), or only 19% of pre-service teachers in Akerson, Morrison, and McDuffie (2006), who recognised the importance of creative and imaginative aspect in scientists' work. In this case, creativity seems to be stereotypically dissociated from perceived scientific qualities. Some pre-service teachers argued that if scientists used creativity and imagination then they would not come up with accurate results (Akerson & Donnelly, 2008).

Scientific Enterprise: Social and Cultural Influences on Science

The social and cultural influences on the scientific enterprise are explicitly recognised by science teachers (Akerson, Morrison, & McDuffie, 2006; Brush, 1989). For example, 51% and 42.3%, respectively, of science teachers in Haidar (1999) and Rubba and Harkness (1993) indicated that a scientist is influenced by social factors. In addition, 79.6% of science teachers in Tairab's study (2001) expressed the view that science and technology affect society and in turn society affects science and technology. However, only 10% and 26%, respectively, of science teachers believed that while collecting or presenting information a scientist is influenced by social biases and governmental pressure. They regarded the authoritative image of the scientist as accurate (Rampal, 1992).

Scientific Enterprise: Interaction between Science and Technology

It is, perhaps, an easy task for in-service science teachers to recognise the interaction between science and technology in such ideas as science is the knowledge base for technology, and technology influences science advancement (Rubba & Harkness, 1993). However, distinguishing between science and technology is probably a very difficult task for them (Rubba & Harkness, 1993; Ma, 2008). 'Technology is applied science' is their commonplace naïve conception about the relationship between science and technology (Tairab, 2001).

Thai In-service Science Teachers' Conceptions of the Nature of Science

Thailand is an independent country, which lies in the heart of Southeast Asia. The country is bordered to the north by Laos and Burma, to the east by Laos and Cambodia, to the south by the Gulf of Thailand and Malaysia, and to the west by the Andaman Sea and Burma. Thailand is considered to be the world's fiftieth largest country in terms of total area and the world's twentieth largest country in terms of population, with approximately 63 million people. The country's official spoken and written language is Thai. Thailand is divided into 76 provinces, which are gathered into six regions – North, North-East, Central, East, West, and South. The capital and largest city of Thailand is Bangkok.

Basic education in Thailand includes 12 years of study. It is divided into four major levels – Level 1 (Grades 1-3), Level 2 (Grades 4-6), Level 3 (Grade 7-9), and Level 4 (Grade 10-12). Thailand has never been colonised, and

therefore its educational system does not draw from European models to a great extent. All schools mandate curricula with a common core, i.e., the Basic Education Curriculum (Ministry of Education, 2001), which consists of eight Learning Strands. In the Science Learning Strand, the NOS is explicitly emphasised in *Learning Sub-strand 8: The Nature of Science and Technology*. The curricula in each school differ somewhat in details, which depend on the school context.

Most of the NOS studies in Thailand are unpublished Master's level theses that were extensively conducted during the 1997-2001 period within a specific area, i.e., the North-East Region. Of the 26 Master's theses that examined teachers' conceptions of NOS, 23 studies were related to in-service teachers' conceptions of the NOS: Grade 10-12 science teachers (13 titles) (e.g. Srithum (1998); Boonmuangsaen (1997)); Grade 7-9 science teachers (8 titles) (e.g. Kuonamon (2000); Pholthum (1997)); Grade 1-6 science teachers (2 titles) (e.g. Sriwinetr (2000); Wangnurat (1999)). All of these studies strongly emphasised a quantitative approach. Surprisingly, all of them utilised the same questionnaire, consisting of 94 items corresponding to the four Scales of the NOS: assumptions of the nature (12 items); scientific knowledge (24 items); scientific method (24 items), and interaction between science-society-technology (34 items). These studies reported respondents' conceptions of the NOS according to those scales as rated on five-point Likert scales. The common goal for these studies was to find the relationship between science teachers' gender, teaching experience, and levels or types of schools they taught at and their conceptions of the NOS. Two major findings emerged from these quantitative studies. First, a majority of science teachers had a high level of understanding of the NOS mentioned in the questionnaire. Second, there was no relationship between gender, teaching experience, and levels or types of schools taught at of science teachers and their conceptions of the NOS.

There was one qualitative study conducted by Promkatkeaw, Sung-ong, and Kaewviyudth (2007) with three primary science teachers' conceptions of the NOS. They found that the participants could not state clearly characteristics and types of scientific knowledge, i.e., facts, concepts, principles, theories, and laws. One of participants viewed scientific knowledge as fixed, concrete, and being originated from proper experiments. For them, science is related to technology because technology brings scientific ideas into numerous useful inventions. They recognised the relationship

between science and society in two characteristics—science for daily lives and science for developing the country.

The current study aimed to use the questionnaire mixing optional plus open-ended responses to explore conceptions of the NOS held by Thai in-service science teachers. The findings of this study may contribute to the relatively limited literature on in-service science teachers' conceptions of the NOS and initially inform involved stakeholders of the current state of in-service science teachers' understanding of the NOS and, subsequently, help them to plan for programmes and curricula to promote understanding of the NOS at the in-service level.

Research Question

The study was guided by this research question: What are in-service science teachers' conceptions of the NOS, particularly scientific knowledge, scientific method, scientists' work, and scientific enterprise?

Methods

Instrument

To explore in-service science teachers' conceptions of the NOS, a newly developed instrument, the Myths of Science Questionnaire (MOSQ) was utilised. The MOSQ consists of 14 items and addresses four aspects of the NOS: (1) scientific knowledge (six items—1, 2, 3, 4, 8, and 9); (2) scientific method (three items—5, 6, and 7); (3) scientists' work (two items—10 and 11); and (4) scientific enterprise (three items—12, 13, and 14). The creation of the MOSQ items was largely inspired by McComas's (1998) article, 'The Principal Elements of the Nature of Science: Dispelling the Myths'. All the MOSQ items are presented in Appendix I. MOSQ respondents are required to select which of three responses, i.e., agree, uncertain, or disagree, best fits their opinion of the item statement and to provide an additional written response to support their selection.

The MOSQ was first validated by five science educators. They were asked to examine the items in terms of their relevance to the dimensions of the NOS and their clarity for and suitability to the respondents. A second version, which had been revised according to the experts' comments, was then pilot tested with 11 in-service science teachers in the central region of Thailand in order to determine whether they understood the items and to assess how

much time they would spend completing the MOSQ. Any ambiguities found during this trial were clarified for the respondents and recorded for further revision of the MOSQ. The completion of the questionnaire took approximately 45 minutes.

Data collection

The data were collected during January to March 2008, from 101 full-time in-service science teachers from nine provinces located in six regions around Thailand. The participants allocated by regions are shown in Table 1.

Table 1
Number of Participating In-service Science Teachers Allocated by Regions

Region	Province	Number of participants
Northern	Chiang Mai	6 (5.9)
	Phitsanulok	13 (12.9)
Central	Bangkok	10 (9.9)
	Nakhon Pathom	16 (15.8)
Northeast	Khon Kaen	8 (7.9)
	Ubon Ratchathani	17 (16.8)
Eastern	Rayong	7 (6.9)
Western	Kanchanaburi	8 (7.9)
Southern	Phuket	16 (15.8)
Total		101 (100)

Note: Numbers in parentheses mean percentages of respondents

The researcher himself collected the data by asking the participant in-service science teachers to respond to the MOSQ and return the completed MOSQ directly to the researcher.

Data Analysis

The frequency of each response (i.e., agree, uncertain, and disagree) was counted and its percentage was subsequently calculated based on the presence of responses. In addition, the “agree” responses for all items were labelled as “uninformed” conceptions of the NOS, and the “disagree” and “uncertain” responses were respectively labelled as “informed” and “uncertain” conceptions of the NOS. However, ‘one’s view of the NOS is a

complex web of ideas that loses meaning when reduced to simple numbers' (Palmquist & Finley, 1997, p. 601). Therefore, the written arguments supporting each response were categorised. In addition, the frequency and percentage for each category were counted and calculated. In the case where the written responses contradict the agree-uncertain-disagree responses, the attention is mainly paid to the written responses and the agree-uncertain-disagree responses were subsequently re-categorised.

Results

Background of Participants

More than three-quarters (76.2%) of in-service science teachers who responded to the MOSQ were female. The age range of participants was from 23 to 60 years. Remarkably, nearly half of the respondents (45.0%) fell within the age range of 46 and 55 years old. More than half of them (55.5%) teach in a secondary level. Their teaching experience varied from 1 to more than 31 years. Although the ages of 45% of the participants ranged between 46 and 55 years old, 27% of them had taught science less than six years. The explanation was that, in the past, science was integrated with health education and social studies to be a so-called 'Life Experience' subject. 'Science' subject has been separated from the other two contents since 2001 according to the proclamation of the new curriculum – the Basic Education Curriculum (Ministry of Education, 2001). The numbers of science teachers in primary (Grade 1-6) and secondary (Grade 7-12) levels were nearly the same – 19.2%, 25.3%, 34.3%, and 21.2% in Level 1 (Grade 1-3), Level 2 (Grade 4-6), Level 3 (Grade 7-9), and Level 4 (Grade 10-12), respectively. A majority of science teachers (81.2%) held a bachelor degree, while 13.9% and 5% held a master degree and a science teacher certificate, respectively. Three-quarters (75.5%) graduated with a science major, while the others graduated in other fields such as social studies (5.3%), physical education (4.3%), Thai studies (2.1%), and industrial arts (2.1%).

In-service Science Teachers' Conceptions of the NOS: Scientific Knowledge

The science teachers' conceptions of the NOS regarding scientific knowledge are shown in Table 2.

Table 2

In-service Science Teachers' Conceptions of the NOS: Scientific Knowledge (N=101)

Item	Response (%)		
	Agree	Uncertain	Disagree
Item 1: Hypotheses are developed to become theories only	26.0	28.0	46.0
Item 2: Scientific theories are less secure than laws	43.0	31.0	26.0
Item 3: Scientific theories can be developed to become laws	84.8	13.2	2.0
Item 4: Scientific knowledge cannot be changed	5.0	5.0	90.0
Item 8: Accumulation of evidence makes scientific knowledge more stable	83.0	11.0	6.0
Item 9: A scientific model (e.g., the atomic model) expresses a copy of reality	45.5	42.6	11.9

Nearly half of science teachers (46%) held the contemporary view about hypotheses and theories. They disagreed with the statement 'hypotheses are developed to become theories only'. With equal number of written responses, 38.9% of science teachers raised two main reasons to support their views – hypotheses may be proven to be false, and hypotheses are likely developed to become laws. However, 28% and 26% of respondents held uncertain and uninformed conceptions regarding hypotheses and theories, respectively.

Nearly one third of in-service science teachers (31%) were uncertain about theories and laws. In addition, 43% of respondents expressed the traditional view that scientific theories are less secure than laws. Their major argument was that 'theories can be changed if scientists discover good enough

evidences, but laws cannot be changed because they have been already proven without any dispute.'

A vast majority of science teachers (84.8%) believed in 'laws-are-mature-theories-fables'. The main argument provided to support their view (81%) was that 'when theories have been proved with credible evidences, they can be developed to become laws'. Interestingly, two science teachers in the disagreed group stated that 'laws can be developed to become theories.' This statement should be characterised as an uninformed conception. This situation shows the potential of an open-ended item in articulating and characterising a respondent's view rather than the use of a multiple-choice item.

Nearly all of science teachers (90%) expressed the contemporary view about the tentativeness of science. Scientific knowledge is seen as tentative, for them, because it can be changed according to the discovery of new knowledge or more credible, supporting evidence through the change of time and nature.

A majority of respondents (83%) possessed the naïve conception that 'accumulation of evidence makes scientific knowledge more stable'. They all believed in what we called 'Baconian induction' (McComas, 1998, p. 58). Of the written responses supporting this naïve view, were that the accumulation of evidence is beneficial for future scientific investigation (25%), increasing the validity (25%) and credibility (20.8%) of scientific knowledge.

Nearly half of the science teachers (42.6%) were uncertain of whether a scientific model expresses a copy of reality. In addition, 45.5% held this naïve conception – a scientific model expresses a copy of reality because it is created from the results of experiment, nature, theories, and laws. Among the 12 science teachers having informed view, five stated that a scientific model does not express a copy of reality because 'it is created from scientists' thinking and imagination.' Interestingly, four of 10 teachers in the uncertain group also argued in a similar way. They should be characterised as having an informed conception.

In-service Science Teachers' Conceptions of the NOS: Scientific Method

The in-service science teachers' conceptions of the NOS with respect to scientific method are depicted in Table 3.

Table 3

In-service Science Teachers' Conceptions of the NOS: Scientific Method (N=101)

Item	Response (%)		
	Agree	Uncertain	Disagree
Item 5: The scientific method is a fixed step-by-step process	44.6	13.8	41.6
Item 6: Science and the scientific method can answer all questions	49.5	30.3	20.2
Item 7: Scientific knowledge comes from experiments only	5.0	12.9	82.1

An uninformed conception of the scientific method was reported by 44.6% of in-service science teachers, who believed that scientists must follow a fixed step-by-step method to obtain scientific knowledge. Three of them, interestingly, commented that a fixed step-by-step scientific method is publicly presented in textbooks. With a nearly equal number to uninformed respondents, 41.6% of informed respondents argued that the scientific method could be reordered or that some steps could be removed. This item statement (Item 5) is a good item to split agreed and disagreed respondents. The 'changeable scientific method' argument was also raised by four teachers in the uncertain group, and should be characterised as informed conception.

Nearly half of the science teachers (49.5%) held an uninformed view that science and scientific method can answer all questions. Of 16 written responses, six teachers argued that science is causal, reasonable, and explainable. In addition, five teachers argued that science is true and provable. Two teachers raised the issue of time, saying that 'it may take time before scientists come up with scientific explanation for some questions.' In contrast, 20.2% stated that science and the scientific method cannot answer all questions. Of 12 written responses, eight teachers raised many issues (e.g., ghosts, spirits, the devil, black magic, the supernatural, fortune-tellers, etc.) that science cannot explain. Interestingly, six of nine written responses falling in the uncertain group also raised these issues.

The contemporary view that ‘scientific knowledge is not originated from experiments only’ was expressed by 82.2% of respondents. Of 63 written statements, the science teachers raised other methods as alternative ways to build scientific knowledge such as observation (33.3%), seeking further information (31.75%), and investigation (14.3%).

In-service Science Teachers’ Conceptions of the NOS: Scientists’ Work

The in-service science teachers’ conceptions of the NOS with respect to scientists’ work are depicted in Table 4.

Table 4
In-service Science Teachers’ Conceptions of the NOS: Scientists’ Work (N=101)

Item	Response (%)		
	Agree	Uncertain	Disagree
Item 10: Scientists do not use creativity and imagination in developing scientific knowledge	10.0	10.0	80.0
Item 11: Scientists are open-minded without any biases	86.1	11.9	2.0

A majority of science teachers (80%) believed that ‘scientists use creativity and imagination in developing scientific knowledge’. Of 23 written responses, eight and five teachers respectively stated that creativity and imagination are involved in the discovery of new scientific knowledge and the creation of novel inventions. However, two teachers argued that, in developing scientific knowledge, scientists always employ the scientific method and never rely on creativity and imagination because they may distort the data.

Nearly all of the science teachers (86.1%) believed that ‘scientists are open-minded without any biases’. However, one of two disagreed teachers stated that ‘it depends on each individual scientist.’ In the uncertain group, three teachers also argued that ‘scientists, as human beings, unavoidably possess some biases; they are not absolutely open-minded.’

In-service Science Teachers' Conceptions of the NOS: Scientific Enterprise

The in-service science teachers' conceptions of the NOS with respect to scientific enterprise are depicted in Table 5.

Table 5

In-service Science Teachers' Conceptions of the NOS: Scientific Enterprise (N=101)

Item	Response (%)		
	Agree	Uncertain	Disagree
Item 12: Science and technology are identical	51.5	21.8	26.7
Item 13: Scientific enterprise is an individual enterprise	2.0	2.0	96.0
Item 14: Society, politics, and culture do not affect the development of scientific knowledge	13.0	13.0	74.0

Of all respondents, more than half (51.5%) held the uninformed conception that science and technology are identical, while 26.7% held an informed conception, and 21.8% were uncertain. Interestingly, the main argument among these three groups of responses was 'technology has originated from science.' Also, in the disagreed group, five of 16 written responses expressed the naïve conception that 'technology is applied science.' This should be characterised as an uninformed conception. This situation, again, shows the potential of an open-ended instrument in articulating a respondent's views regarding the NOS. Of 44 written responses, three patterns of relationship between science and technology emerged, i.e., technology originated from science (45.45%), science and technology support and develop each other (22.7%), and science and technology are a part of each other (4.5%).

Nearly all the science teachers (96%) disagreed with the statement 'scientific enterprise is an individual enterprise'. They claimed four advantages of collaboration in conducting scientific enterprise: deriving more quality data (24.4%), gaining a variety of perspectives (20%), enhancing opportunity to success (15.9%), and enhancing the credibility of results (2.2%). Two teachers additionally supported their view of science as social enterprise by the 'science is an activity for all' statement.

Nearly three-quarters of the science teachers (74%) believed that society, politics, and culture potentially affect the development of scientific knowledge in some ways. Twelve of 32 written responses (37.5%) argued that society, politics, and culture support science, for example, a government provides a budget for scientific investigation (18.8%). In contrast, eight teachers (25%) stated that specific cultural or value frameworks in some societies do impede science advancement.

In-service Science Teachers' Conceptions of the NOS: Holistic View

The overall responses of all science teachers are depicted in Figure 1.

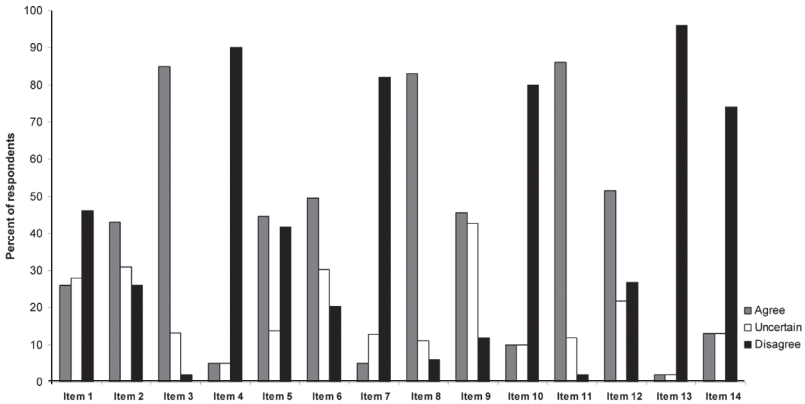


Figure 1. In-service science teachers' conceptions of the NOS.

In addition, the relationship between uninformed, uncertain, and informed responses is shown in Table 6.

Table 6
Relationship between Uninformed, Uncertain, and Informed Conceptions of the NOS (N=101)

Uninformed	%	Uncertain	%	Informed	%
Item 11	86.1	Item 9	42.6	Item 13	96.0
Item 3	84.8	Item 2	31.0	Item 4	90.0
Item 8	83.0	Item 6	30.3	Item 7	82.1
Item 12	51.5	Item 1	28.0	Item 10	80.0
Item 6	49.5	Item 12	21.8	Item 14	74.0
Item 9	45.5	Item 5	13.8	Item 1	46.0
Item 5	44.6	Item 14	13.0	Item 5	41.6
Item 2	43.0	Item 7	12.9	Item 12	26.7

There was a good distribution across three responses in Items 1 and 2 and a good split between uninformed and informed responses in Item 5. Additionally, four characteristics of responses across 14 items of the MOSQ were noticed: High Informed with High Confidence (HIHC), High Informed with Low Confidence (HILC), Low Informed with High Confidence (LIHC), and Low Informed with Low Confidence (LILC). Five items may be characterised as a HIHC group, i.e., items 4 (tentativeness of science), 7 (scientific experiment), 10 (creativity and imagination in science), 13 (science as social enterprise), and 14 (social, political, and cultural influences on science). There was only one item that fell into a HILC group, i.e., item 1 (hypotheses and theories). Three items may be characterised as a LIHC group, i.e., items 3 (theories and laws), 8 (cumulative knowledge), and 11 (theory-laden observation and subjectivity). Finally, five items fell into a LILC group, i.e., items 2 (theories and laws), 5 (universal, step-wise scientific method), 6 (scientific explanation), 9 (scientific model), and 12 (science and technology). These four characteristics of responses are depicted as Figure 2.

	High Informed (HI)	Low Informed (LI)
High Confident (HC)	Items 4, 7, 10, 13, 14	Items 3, 8, 11
Low Confident (LC)	Item 1	Items 2, 5, 6, 9, 12

Figure 2. Four characteristics of responses across the MOSQ items.

Discussion

Most science teachers in this study, like others around the world, believed in the 'laws-are-mature-theories-fables' that led them to perceive theories as less secure than laws (Abd-El-Khalick & BouJaoude, 1997; Akerson & Donnelly, 2008; Dogan & Abd-El-Khalick, 2008; Haidar, 1999; Promkatkeaw, Sungong, & Kaewviyudth, 2007; Rubba & Harkness, 1993). Few teachers, however, indicated the inverse relationship between theories and laws – laws can be developed to become theories.

Similarly to Dogan and Abd-El-Khalick (2008), the tentativeness or dynamics of science is recognised by almost all science teachers in this study. However, they did not raise subjectivity as an important factor for tentative science, as Bell, Lederman, and Abd-El-Khalic (2000) noticed, but the discovery of new credible evidence instead. The caution about characterising teachers' ideas about the tentativeness of science is that the 'laws-are-mature-theories-fables' might lead them to mistakenly answer the tentativeness of science item correctly (Bell, Lederman, & Abd-El-Khalick, 2000; Thye & Kwen, 2003).

Scientific progress can be best described as a revisionary process rather than a cumulative process (Brickhouse, 1990; Haidar, 1999). However, a majority of science teachers in this study strongly believed in Baconian induction. Similar to the participants in Akerson and Donnelly (2008) and Ma (2008), they viewed scientific knowledge as cumulative knowledge, i.e., individual pieces of evidence are collected and examined until a theory or law is discovered. They raised many advantages of science as accumulative process, i.e., furthering more in-depth investigation and increasing the validity and credibility of scientific knowledge. They were unaware of the problem of Baconian induction, i.e., 'even a preponderance of evidence does not guarantee the production of valid knowledge' (McComas, 1998, p. 58).

'A scientific model is an exact copy of reality' was a statement of which nearly half of science teachers in this study were unsure. Nearly half of them viewed a scientific model as a copy of reality (Abd-El-Khalick & BouJaoude, 1997; Dogan & Abd-El-Khalick, 2008) because it is created from experimental results, theories, and laws. Only few teachers, as in Haidar's (1999) study, realised that a scientific model is not exactly a copy of reality because it is created from a scientist's thinking and imagination.

In this study, the step-wise scientific method item appeared as a good item for discriminating informed and uninformed respondents. Some science teachers strongly believed in the universal, step-wise scientific method (Abd-El-Khalick & BouJaoude, 1997; Akerson & Donnelly, 2008; Dogan & Abd-El-Khalick, 2008) because it is widely propagated in school science textbooks (Haidar, 1999) or in the form of cookbook or verification-type laboratory activities (Palmquist & Finley, 1997). The belief in a universal, step-wise scientific method may lead science teachers to perceive science as objective rather than subjective. In contrast to Gallagher (1991), Mellado (1997) and Haidar (1999), the fixed process of the scientific method, in the view of some teachers in this study, is not linked with the objectivity of scientific knowledge and the character of good scientists. The term 'scientific method' itself may be an issue. Abd-El-Khalick and BouJaoude (1997) found that without explicitly stating the term "scientific method", almost all teachers in their study adopted the more informed view that science activities are not completely logical and sequential.

The science teachers in this study strongly believed that the causality and provability according to the use of scientific method enhance the capability of science in answering all questions. For some difficult questions, a few teachers indicated time as a major factor, predicting that at some point in the future, scientists will come up with scientific explanations. This finding is similar to Ma's (2008) study, i.e., most science teachers strongly believed that it is only a matter of time for science to reveal or thoroughly understand the essence of the nature. Also, similarly to Lunn's (2002) study, some science teachers raised many phenomena that science cannot explain. In addition, a vast majority of science teachers believed that scientific knowledge is not only originated from experiment. They provided other alternative methods to build scientific knowledge such as observation, seeking further information, and investigation (Thye & Kwen, 2003).

In contrast to Rampal (1992), Abd-El-Khalick and Boujaoude (1997), and Akerson, Morrison, & McDuffie (2006), most science teachers in this study realised the importance of creativity and imagination in developing scientific knowledge through the discovery of new knowledge and the creation of novel inventions. There were a few teachers who disagreed and believed that scientists must follow a fixed-step scientific method in developing scientific knowledge (Abd-El-Khalick & BouJaoude, 1997).

Almost all science teachers in this study believed in objectivity in science (Abd-El-Khalick & BouJaoude, 1997; Brickhouse, 1990; Dogan & Abd-El-Khalick, 2008; Gallagher, 1991; Haidar, 1999; Promkatkeaw, Sungong, & Kaewviyudth, 2007; Rampal, 1992). They viewed scientists as being open-minded without any biases. They showed their disagreement about the involvement of human subjectivity in science (Ma, 2008). Only a few teachers, as in Lunn's (2002) study, mentioned scientists as human beings who unavoidably possess some bias.

As Rubba and Harkness (1993) noted, science and technology cannot be easily distinguished by most teachers. More than half of the science teachers in this study held the uninformed conception that science and technology are identical. Their main argument was that technology originates from science, as Rubba and Harkness (1993) mentioned, or science is the knowledge base for technology. Similarly to Tairab (2001) and Promkatkeaw et al. (2007), some teachers believed that technology is applied science. This finding has strong cultural roots because people tend to 'point to artefacts and systems that followed scientific discoveries', for example, atomic physics leading to nuclear power generation, and electrical research leading to dynamos and transformers. Consequently, science educators should present a clear distinction between science and technology and advocate the complexity and the interactive nature of the relationship between science and technology, or 'interactionist perspective' (Tairab, 2001, p. 245). In addition, of the three patterns of relationships between science and technology emerged in this study, one of them, i.e., science and technology support and develop each other, might be similar to that described by Rubba and Harkness (1993).

A majority of in-service science teachers believed that science is an activity being greatly influenced by society, culture, and politics (Brush, 1989; Rubba & Harkness, 1993; Tairab, 2001; Akerson, Morrison, & McDuffie, 2006) in two possible ways – positive (e.g. a governmental research grant) and negative (e.g. cultural and value frameworks impeding science advancement). Only a few teachers, as in Rampal's (1992) study, did not recognise the influence of society, culture, and politics on science advancement. In contrast to Tairab (2001) a majority of science teachers in this study realised the importance of collaboration in scientific enterprise according to four major advantages: deriving more quality data, gaining a variety of perspectives, enhancing opportunity to success, and enhancing the credibility of results.

Implications

Science teachers' conceptions of the NOS potentially influence their actions in classrooms. Therefore, helping science teachers to acquire an adequate understanding of the NOS should be a basic requirement for teacher professional development programmes. This study revealed that a significant number of in-service science teachers need urgent help from the involved stakeholders because of their uninformed conceptions of the NOS, especially those who fell into a LIHC group – items 3 (theories and laws), 8 (cumulative knowledge), and 11 (theory-laden observation and subjectivity). These uninformed conceptions of the NOS held by in-service teachers mentioned previously are consistent with many studies in local and global contexts. These aspects of the NOS should be regarded as major difficulties for teachers to understand the NOS. The involved stakeholders, for example science educators, in both local (e.g. Institute for the Promotion of Science and Technology (IPST), Thailand) and also global contexts should employ these aspects as a basis for designing a professional development programme to help science teachers develop their understanding of the NOS. Similarly, science teachers also need particular help with the items being characterised as a LILC group – items 2 (theories and laws), 5 (universal, step-wise scientific method), 6 (scientific explanation), 9 (scientific model), and 12 (science and technology). The low confidence according to the nature of science teachers taught should be regarded as undesirable for the science teachers as well.

According to the Learning Sub-strand 8: The Nature of Science and Technology mentioned in Thai science curriculum, all Thai science teachers have the major responsibility to help students understand the way of doing science as well as its nature in order to cultivate “little scientists” in their classroom. How could this ultimate goal be achieved if science teachers still possess many uninformed conceptions of the NOS? At least, the findings of this study help inform Thai science teachers to be aware and examine their conceptions of the NOS particularly those frequently misunderstood by others.

Compared with a multiple-choice item, the two-tier items (i.e. option plus written responses) included in the MOSQ create the potential to articulate a respondent's conceptions of the NOS. However, because of a shortage of time and a large number of respondents, in the further step, the empirically focussed multiple-choice MOSQ will be constructed by using written responses in each item as multiple-choices. The newly constructed

MOSQ might be more convenient and useful for professional development programmes in articulating participating teachers' conceptions of the NOS. Nonetheless, the present MOSQ is useful in capturing, to some degree, in-service science teachers' conceptions of the NOS. It is also able to provide both quantitative and qualitative data relating to respondents' conceptions of the NOS.

The NOS should not be anticipated as a side effect or secondary product of hands-on inquiry programmes (Akindehin, 1988) as in the past; rather, it should be explicitly mentioned and included in all science professional development programmes. Based on empirical evidence (Akindehin, 1988; Billeh & Hassan, 1975; Carey & Strauss, 1968; King, 1991; Morrison, Raab, & Ingram, 2009; Ogunniyi, 1982), explicit, reflective instruction on the NOS has the potential to improve science teachers' conceptions of the NOS. The examples of explicit teaching approaches are individual and collaborative writing assignments defining characteristics for science and pseudo-science (Craven, Hand, & Prain, 2002); explicit discussion of the NOS and role of the NOS in science teaching within conceptual change and cooperative learning environment (Palmquist & Finley, 1997); small-group peer discussions and debates (Craven, Hand, & Prain, 2002), and interaction with scientists in an authentic context (Morrison, Raab, & Ingram, 2009). However, explicitly teaching the NOS outside a science context has only a limited effect on changing and improving science teachers' understanding of the NOS. Therefore, NOS-associated activities and discussions should not be an add-on, but should be tightly linked to science content (Driver, Leach, Miller, & Scott, 1996).

Science teachers' different views of science arise from their views about how children learn. Another aspect that should be included in science teacher professional development programmes is the constructivist epistemology. Growing awareness of, and commitment to, constructivism among science teachers might help them improve their conceptions of the NOS (Pomeroy, 1993), especially the tentativeness of science and theory-laden observation.

The other implication is to study the relationship between in-service science teachers' conceptions of the NOS and their classroom practices. Although this question is still unclear in the literature, it is worth studying, especially in the Thai context. Noticeably, there are, of course, limitations to this study. The assertions made cannot be generalised from this small sample, which was not randomly selected to represent all in-service science teachers in Thailand.

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Appendix I

Myths of Science Questionnaire (MOSQ)

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

Statement	Opinion
1. Hypotheses are developed to become theories only	<input type="checkbox"/> Agree <input type="checkbox"/> Uncertain <input type="checkbox"/> Disagree <hr/>
2. Scientific theories are less secure than laws	<input type="checkbox"/> Agree <input type="checkbox"/> Uncertain <input type="checkbox"/> Disagree <hr/>
3. Scientific theories can be developed to become laws	<input type="checkbox"/> Agree <input type="checkbox"/> Uncertain <input type="checkbox"/> Disagree <hr/>
4. Scientific knowledge cannot be changed	<input type="checkbox"/> Agree <input type="checkbox"/> Uncertain <input type="checkbox"/> Disagree <hr/>
5. The scientific method is a fixed step-by-step process	<input type="checkbox"/> Agree <input type="checkbox"/> Uncertain <input type="checkbox"/> Disagree <hr/>
6. Science and the scientific method can answer all questions	<input type="checkbox"/> Agree <input type="checkbox"/> Uncertain <input type="checkbox"/> Disagree <hr/>
7. Scientific knowledge comes from experiments only	<input type="checkbox"/> Agree <input type="checkbox"/> Uncertain <input type="checkbox"/> Disagree <hr/>

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
