

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

Abstract

The author explores the history of nature of science beliefs among pre-service and in-service teachers primarily in the United States and Thailand and compares this history to findings in a current study being conducted in Thailand.

Two research questions were used to guide this current study: What are pre-service and in-service science teachers' conceptions of the NOS, particularly with regard to scientific knowledge, the scientific method, scientists' work, and scientific enterprise? What are similarities and differences between pre-service and in-service science teachers' conceptions of the NOS. The findings of this study may inform stakeholders about the current state of pre-service and in-service science teachers' understanding of the NOS and, subsequently, inform the design and implementation of programmes and curricula that promote understanding of the NOS at both the pre-service and in-service levels.

Introduction

Science is an important subject for all levels of education. However, numerous studies have shown that many students and even teachers

understand science and its nature inadequately. This situation might be harmful, as McComas, Almazroa, and Clough (1998) pointed out, "particularly in societies where citizens have a voice in science funding decisions, evaluating policy matters and weighing scientific evidence provided in legal proceedings" (p. 511). 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).

Presently, many science curricula, such as Thai Science Curriculum (Office of the Education Council, 2002), aim to help learners attain an adequate understanding of the NOS. To effectively address the NOS, science teachers must themselves possess adequate understanding of the NOS (Abd-El-Khalick & Lederman, 2000) and model appropriate science-related behaviours and attitudes in classrooms (Murcia & Schibeci, 1999). Actions presented by teachers in their classrooms have a strong influence on their 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). In the case of language, for example, the way that teachers verbally present scientific enterprise has an impact on the way that students formulate their views about science (Munby, 1967; Zeidler & Lederman, 1989). Therefore, as McComas, Almazroa, and Clough (1998) emphasised, promoting science teachers' understanding of the NOS is clearly a prerequisite for effective science teaching.

The Nature of Science

In general, the NOS involves the process through which scientific knowledge is generated and the character of science (Lederman, 1992). Additionally, McComas, Almazroa, and Clough (1998) presented some agreeable aspects of the NOS derived from an analysis of eight international science standard documents: 1) Scientific knowledge is tentative. 2) Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments, and scepticism. 3) There is no universal step-by-step scientific method. 4) Laws and theories serve different roles in science.

Key words: nature of science, pre-service teachers, in-service teachers, conceptions

5) Observations are theory-laden. 6) Scientists are creative. 7) Science and technology impact on each other. 8) Scientific ideas are affected by their social and historical milieu.

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

The literature suggests that most pre-service and in-service science teachers possess an inadequate understanding of the NOS. Their conceptions of the NOS are also mixed, fluid, and incoherent (Abd-El-Khalick & BouJaoude, 1997; Dogan & Abd-El-Khalick, 2008; Haidar, 1999; Lederman, 1992). Pre-service and in-service science teachers' conceptions of the NOS can be categorised in four major groups: scientific knowledge, scientific method, scientists' work, and scientific enterprise.

Scientific knowledge: Hypotheses, theories, and laws.

Researcher have found that pre-service and in-service teachers commonly believed in the hierarchical relationship between hypotheses, theories, and laws, i.e., When a hypothesis is empirically tested and proven correct, it becomes a theory. After a theory has been proved true many times by different people and has been around for a long time, it becomes a law (Abd-El-Khalick & BouJaoude, 1997; Dogan & Abd-El-Khalick, 2008; Haidar, 1999; Rubba & Harkness, 1993; Thye & Kwen, 2003). Therefore, they did not recognise that these constructs are different types of ideas that play different roles in science such that laws are statements or descriptions of discernible patterns developed to

account for observable phenomena, while theories are inferred explanations for those phenomena (Abd-El-Khalick & BouJaoude, 1997).

Belief in a hierarchical relationship between hypotheses, theories, and laws potentially leads teachers to incorrectly perceive that theories are general propositions that are more credible than hypotheses but less credible than laws (Ogunniyi, 1982). Credibility of hypotheses, theories, and laws relies heavily on the availability or accumulation of supporting evidence (Dogan & Abd-El-Khalick, 2008). For example, a significant number of teachers believed in the 'laws-are-mature-theories-fable', i.e., when enough supporting evidence is accumulated, theories become laws (Abd-El-Khalick, Bell, & Lederman, 1998; Thye & Kwen, 2003).

Scientific knowledge: Tentativeness of science.

Regarding the status of scientific knowledge, pre-service and in-service teachers can be characterised into two groups: "static" and "dynamic." The former group views science as stable or having a static status (Behnke, 1961; Craven, Hand, & Prain, 2002; Murcia & Schibeci, 1999; Tairab, 2001), and the latter group views science as tentative or having a dynamic status (Bell, Lederman & Abd-El-Khalick, 2000; Mellado, 1997; Palmquist & Finley, 1997). In the static-science group, teachers believed that science is a collection of facts that explains the world with little or no elaboration (Tairab, 2001). Consequently, the major purpose of scientific research is seen as amassing as much data as possible (Craven, Hand, & Prain, 2002; Tairab, 2001). On the contrary,

the dynamic-science group views science as tentative (Dogan & Abd-El-Khalick, 2008). For example, four out of five teachers in Lunn's study (2002) believed that science is constantly evolving to adequately give a full world-view, especially with regard to some mysterious patterns in nature. Theories can be renewed and changed in the light of new knowledge. Subjectivity and creativity are commonly regarded as important factors contributing to the tentative nature of science (Abd-El-Khalick, Bell, & Lederman, 1998).

Scientific knowledge: Cumulative knowledge.

Some pre-service and in-service science teachers held the conception that scientific knowledge is cumulative knowledge and its advancement depends heavily on the accumulation of supporting evidence or increasing observation rather than changes in theory (Brickhouse, 1990; Haidar, 1999).

Scientific knowledge: Scientific model.

Many pre-service and in-service teachers strongly believed that scientific models are copies of reality rather than human inventions (Abd-El-Khalick & BouJaoude, 1997; Dogan & Abd-El-Khalick, 2008), because scientists or scientific research have shown they are true or because various media, especially science textbooks, have publicly presented them (Dogan & Abd-El-Khalick, 2008). As found in Thye and Kwen's 2003 study, nearly half of the pre-service teachers (42%) were not aware of the limitations of scientific modelling, for example, "since they [scientists] can provide the structure

of atom universally in textbooks and reference books, I think that they must be very certain of it. Maybe they look at a microscopic view” (p. 6). Similarly, most pre-service teachers (70%) in Ogunniyi’s study (1982) believed that molecules, atoms, and electrons are empirical concepts. However, many teachers, particularly 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 (Bell, Lederman, & Abd-El-Khalick, 2000; Haidar, 1999).

Scientific method: Universal, step-wise method.

The scientific method is commonly perceived by pre-service and in-service science teachers as a lock-step procedure or a universal step-wise method (Abd-El-Khalick & BouJaoude, 1997; Craven, Hand, & Prain, 2002; Dogan & Abd-El-Khalick, 2008; Haidar, 1999). Of all categories, the percentage of pre-service teachers who believed in a universal step-wise scientific method varied the most from study to study. Studies have shown these percentages to be 23.5% (Murcia & Schibeci, 1999), 33% (Craven, Hand, & Prain, 2002), 60% (Palmquist & Finley, 1997), 65% (Haidar, 1999), or even 100% (Mellado, 1997). They mostly viewed the scientific method as a series of ordered, rigid steps that lead to objectivity and valid scientific claims (Mellado, 1997; Palmquist & Finley, 1997) or unambiguous scientific truth (Brickhouse, 1990). Also, good scientists are defined as those who follow a *recipe*, or the steps of the scientific method, in their investigations (Abd-El-Khalick &

BouJaoude, 1997; Haidar, 1999). This can also be attributed to a science curriculum that presents the scientific method as a sequence of steps that all students have to follow exactly in order to reach certain results (Haidar, 1999).

Scientific method: Scientific experiment.

Some teachers held uninformed views regarding scientific experimentation. In Thye and Kwen’s (2003) study, most pre-service teachers (79%) considered scientific experimentation to be necessary to support the validity of scientific knowledge. They stated that “experiments are necessary to confirm truth and validity of scientific theory and inquiry. Without experimental validity, there is no scientific knowledge. There is only blind faith” (Thye & Kwen, 2003, p. 5).

Scientists’ work: Theory-laden observation and subjectivity.

One of the common bipolar views of the NOS is subjectivity versus objectivity or theory-laden versus theory-free. Some pre-service and in-service teachers believed that subjectivity plays a major role in the development of scientific knowledge (Abd-El-Khalick & BouJaoude, 1997; Palmquist & Finley, 1997). As an example, the personal attributes of scientists (e.g., personalities, background, motivations, beliefs, worldviews, paradigms, etc.) may affect them during the processes of selecting, interpreting, recording, and reporting evidence (Abd-El-Khalick, Bell, & Lederman, 1998; Murcia & Schibeci, 1999), generating conclusions or theories (Abd-El-Khalick, Bell, & Lederman, 1998; Thye & Kwen, 2003), and thinking

and decision-making (Lunn, 2002). Similarly, in Thye and Kwen’s study, nearly half of pre-service teachers (46%) believed that “the same piece of evidence or the same set of data can be subject to [scientists’] multiple interpretations” (2003, p. 7). In contrast, many teachers strongly believed in objectivity in science, because it is directly related to the validity of scientific knowledge (Brickhouse, 1990; Dogan & Abd-El-Khalick, 2008; Haidar, 1999; Mellado, 1997; Murcia & Schibeci, 1999). To them, good scientists are seen as objective in their work. Hence, observations and interpretations that scientists make should not be influenced by the theories or frames of reference they hold (Abd-El-Khalick & BouJaoude, 1997; Palmquist & Finley, 1997; Rampal, 1992).

Scientists’ work: Creativity and imagination in science.

The pre-service and in-service teachers who dismissed objectivity in science acknowledged the role of creativity and imagination in building scientific knowledge (Abd-El-Khalick, Bell, & Lederman, 1998; Bell, Lederman, & Abd-El-Khalick, 2000), particularly as it relates to designing research or experiments, generating new ideas, and developing technology (Murcia & Schibeci, 1999). Conversely, some teachers overlook the role of creativity and imagination in science. Creativity, for them, seems to be “stereotypically dissociated from perceived scientific qualities” (Rampal, 1992, p. 424). Some pre-service teachers similarly argued that “science was fact or truth and creativity did not have a place” (Murcia & Schibeci, 1999, p. 1132). Additionally, Thye and Kwen

(2003) reported that one third of the pre-service teachers did not seem to think that creativity and imagination were required at any steps of scientific investigation. Also, a few of them adamantly stated that “there must not be any interpretation of the facts, they should speak for themselves” (p. 7).

Scientific enterprise: Social and cultural influences on science.

The social and cultural influences on scientific enterprise are recognised by most pre-service and in-service teachers (Brush, 1989; Haidar, 1999; Mellado, 1997; Murcia & Schibeci, 1999; Rubba & Harkness, 1993; Tairab, 2001). These influences may come from the larger society or the culture of science itself, including the influences of professional organisations, funding sources, and peer review (Bell, Lederman, & Abd-El-Khalick, 2000). Murcia and Schibeci (1999) found that three-quarters of pre-service teachers believed that “the bodies [government departments] that supply the money for research influence the direction of science” (p. 1135), and between 51% (Haidar, 1999) and 42.3% (Rubba & Harkness, 1993) of in-service teachers indicated that scientists are influenced by social factors. Additionally, in Tairab’s (2001) study, more than three-quarters (79.6%) of the science teachers stated that science and technology affect society and, in turn, society affects science and technology. Conversely, the influences of social and cultural factors on scientific practice are overlooked by many pre-service and in-service teachers (Abd-El-Khalick, Bell, & Lederman, 1998). These teachers were found to neglect the role of science as a social enterprise or a form of human cultural

activity (Tairab, 2001). Some teachers held high regard for the authoritative image of the scientist. For example, only 10% of pre-service and 26% of in-service science teachers reported that they believed that scientists were influenced by social biases and governmental pressure when collecting or presenting information (Rampal, 1992).

Scientific Enterprise: Interaction between science and technology.

It is, perhaps, an easy task for pre-service and in-service science teachers to recognise the interaction between science and technology in conceptions such as the idea that science is the knowledge base for technology and the idea that technology influences scientific advancement. However, distinguishing between science and technology is a very difficult task for many teachers (Rubba & Harkness, 1993). They commonly held the conception that technology is applied science (Tairab, 2001).

Thai Pre-service and In-service Science Teachers’ Conceptions of the Nature of Science

Thailand is an independent country that 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 (approximately 63 million). 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.

Thailand has never been colonized, and, therefore, its educational system does not draw from European models to a great extent. Basic education in Thailand includes 12 years of study. According to the Basic Education Curriculum (Ministry of Education, 2001), basic education in Thailand 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). According to Section 43 of the Teacher and Educational Personnel Act (Secretariat of the Cabinet of Thailand, 2003), teaching in Thailand is presently regarded as a highly-qualified profession, and, as such, it requires a Teacher Professional License. Teachers, including pre-service teachers, must be qualified in accordance with the Knowledge and Professional Experience Standards and Ethics.

Most of the NOS studies in Thailand are unpublished Master’s theses that were conducted extensively during the 1997-2001 period in the Northeast. Of 26 studies regarding teachers’ conceptions of the NOS, almost all of them (23 studies) dealt with in-service teachers. Twenty-one studies involved secondary teachers (e.g., Boonmuangsaen (1997), Kuonamon (2000), Pholthum (1997), Srithum (1998)), and the other two studies involved primary teachers (Sriwinetr, 2000; Wangnurat, 1999). There were only three studies that dealt with pre-service teachers (Jongchidklang, 2000; Phiankaew, 1999; Wansudol, 2000). All studies used a quantitative approach by employing the same questionnaire that consisted of

94 items corresponding to the four Scales of the NOS: Assumptions of the nature scale (12 items), Scientific knowledge scale (24 items), Scientific method scale (24 items), and Interaction between science-society-technology scale (34 items). These studies reported respondents' conceptions of the NOS according to those scales as rated on five-point Likert scales.

The key findings related to pre-service teachers' conceptions of the NOS were that they generally showed a high level of understanding of the four Scales of the NOS (Jongchidklang, 2000; Phiankaew, 1999; Wansudol, 2000), and statistical interactions between the variables of gender and learning programme on their understanding of the NOS were not found to be significant (Wansudol, 2000). Similarly, the studies of in-service teachers' conceptions of the NOS generally reported that they had a high level of understanding of the four Scales of the NOS. There was also no relationship between gender, teaching experience, and levels or types of schools taught and conceptions of the NOS. The latter finding was consistent with those of Carey and Stauss (1970), Lederman (1992), and Mellado (1997), all of whom reported that there is no significant relationship between in-service teachers' academic background or personal antecedents in school and their conceptions of the NOS.

There was one qualitative study exploring three primary in-service science teachers' conceptions of the NOS (Promkatkeaw, Sungong, & Kaewviyudth, 2007). The key findings were that the participants could not state clearly the characteristics and types of scientific knowledge,

i.e., facts, concepts, principles, theories, and laws. One participant viewed scientific knowledge as being fixed, concrete, and originating from proper experiments. All of them commonly recognised the relationship between science and technology as the application of scientific ideas in the form of useful inventions. Additionally, they showed understanding of the relationship between science and society in terms of the use of science for daily lives and developing the country.

The current study aims to explore conceptions of the NOS held by Thai pre-service and in-service science teachers. Two research questions were used to guide this study: What are pre-service and in-service science teachers' conceptions of the NOS, particularly with regard to scientific knowledge, the scientific method, scientists' work, and scientific enterprise? What are similarities and differences between pre-service and in-service science teachers' conceptions of the NOS. The findings of this study may inform stakeholders about the current state of pre-service and in-service science teachers' understanding of the NOS and, subsequently, inform the design and implementation of programmes and curricula that promote understanding of the NOS at both the pre-service and in-service levels.

Method

Instrument.

The Myths of Science Questionnaire (MOSQ) was used to explore pre-service and in-service science teachers' conceptions of the NOS. It consists of fourteen items and addresses four aspects of the NOS: scientific knowledge (items 1, 2, 3,

4, 8, and 9), scientific method (items 5, 6, and 7), scientists' work (items 10 and 11), and scientific enterprise (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 as Figure 1 in the Appendix. MOSQ respondents are required to select one of three responses (agree, uncertain, or disagree) that 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 21 pre-service and 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. Completion of the questionnaire took approximately 45 minutes.

Data collection.

The data were collected during the first semester of the 2008 academic year. The researchers administered the MOSQ and collected it from all of the respondents. The respondents were 113 pre-service science teachers in a five-year science teacher preparation programme at one university in the central region of Thailand and 101 in-service science teachers from

nine provinces located in six regions around Thailand. Allocation by region of the participating in-service teachers is 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
	Phitsanulok	13
Central	Bangkok	10
	Nakhon Pathom	16
Northeast	Khon Kaen	8
	Ubon Ratchathani	17
Eastern	Rayong	7
Western	Kanchanaburi	8
Southern	Phuket	16
Total		101

The majority of pre-service science teachers (83.2%) that responded to the MOSQ were female. Of the pre-service teachers, 24.8%, 15%, 21.2%, 17.7%, and 21.2% were in their first, second, third, fourth, and fifth years of study, respectively. Their fields of study were biology (33.3%), chemistry (30.7%), general science (20.0%), and physics (16.0%). In this case, the first-year pre-service teachers had not yet selected a major field of study.

More than three-quarters (76.2%) of in-service science teachers who responded to the MOSQ were female. Their age range was from 23 to 60 years, and nearly half of them (45%) fell within the age range of 46 and 55 years old. Their teaching experience varied from less than 1 year to more than 31 years. Although the ages of nearly half of the participants ranged between 46 and 55 years old, 27% had taught science less than six years. The explanation for this is that, in the past, science

was integrated with health education and social studies as a “Life Experience” subject. More recently, “Science” as a specific subject has been separated from those two contents in accordance with the proclamation of the 2001 Basic Education Curriculum (Ministry of Education, 2001). The numbers of the teachers in primary (Level 1-2) and secondary (Level 3-4) levels were nearly equal, i.e., Level 1 (19.2%), Level 2 (25.3%), Level 3 (34.3%), and Level 4 (21.2%). Most participants (81.2%) held a bachelor degree, and 13.9% and 5% of them held a master degree and a science teacher certificate, respectively. Of all in-service teachers, three-quarters graduated with a science major. The others graduated in other fields, including social studies (5.3%), physical education (4.3%), Thai studies (2.1%), and industrial arts (2.1%).

Data analysis.

The frequency of each response (agree, uncertain, and disagree) was counted and calculated as a percentage. The agree, uncertain, and disagree responses were respectively

interpreted as informed, uncertain, and uninformed 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, and the frequency and percentage for each category were also counted and calculated.

Results and Discussion

Pre-service and in-service science teachers’ conceptions of the NOS: Scientific knowledge.

About half of the pre-service and in-service teachers (55.4% and 46%) held the informed conception of hypotheses and theories. They did not believe that hypotheses are developed to become theories only and raised two major arguments. Firstly, 44.2% and 38.9% of the pre-service and in-service teachers argued that hypotheses are potentially developed to become laws. Secondly, the idea that hypotheses may be proven to be false was supported by 13% and 38.9% of the pre-service and in-service teachers. However, about one

Table 2: Pre-service and in-service science teachers’ conceptions of the NOS: Scientific knowledge

Item	Uninformed (%)		Uncertain (%)		Informed (%)	
	Pre ¹	In ²	Pre	In	Pre	In
Item 1: Hypotheses and theories	11.6	26.0	33.0	28.0	55.4	46.0
Item 2: Theories less secure than laws	43.8	43.0	30.4	31.0	25.9	26.0
Item 3: Theories become laws	80.4	84.8	16.1	13.1	3.6	2.1
Item 4: Tentativeness of science	1.8	5.0	4.5	5.0	93.8	90.0
Item 8: Science as accumulative knowledge	81.1	83.0	15.3	11.0	3.6	6.0
Item 9: Scientific model	33.3	45.5	30.6	42.6	36.0	11.9

Note: ¹ “Pre” means Pre-service science teachers, ² “In” means In-service science teachers

third of the pre-service and in-service teachers (33% and 28%) were uncertain whether or not hypotheses are developed to become theories only.

Nearly half of the pre-service and in-service teachers (43.8% and 43%) expressed the uninformed view that scientific theories are less secure than laws. The ‘theories can be changed, but laws are fixed’ argument was supported by 29.2% and 18.8% of pre-service and in-service teachers. Specifically, 34.4% of in-service teachers reasoned that theories can be changed if scientists discover enough supporting evidence, and 28.1% of them reasoned that laws cannot be changed, because they have been already proven without any dispute. There were only five pre-service teachers who explicitly demonstrated the informed conception that ‘theories and laws are equally credible’. In addition, nearly one third of the pre-service and in-service teachers (30.4% and 31%) were unsure whether theories are less secure than laws.

Most of the pre-service and in-service science teachers (80.4% and 84.8%) held the uninformed view that laws are mature theories. In the written responses, 70% of pre-service teachers argued that when theories have been proven, they can be developed to become laws, and 81% of the in-service teachers suggested that a theory could be proven by collecting enough credible evidence. Two in-service teachers, however, indicated the reverse process, i.e. laws can be developed to become theories.

Nearly all of the pre-service and in-service science teachers (93.8% and 90%) expressed the informed view about the tentativeness of science. Their major argument was

that scientific knowledge could be changed by the discovery of new knowledge or more credible, supporting evidence. However, one pre-service teacher stated that “theories can be developed to become law, thus scientific knowledge is tentative.” This response demonstrates the conjunction of two beliefs; the first belief is incorrect, but accidentally leads to a correct belief.

The majority of pre-service and in-service teachers (81.1% and 83%) possessed the uninformed conception that an “accumulation of evidence makes scientific knowledge more stable.” They believed in what is called “Baconian induction” (McComas, 1998, p. 58). In the written responses, the pre-service and in-service teachers who expressed the idea that ‘the accumulation of evidence increases the credibility of scientific knowledge’ were 59.5% and 20.8%, respectively. In addition, a quarter of the in-service teachers indicated that the accumulation of evidence is beneficial for future scientific investigation and increases the validity of scientific knowledge.

The majority of in-service teachers (45.5%) expressed the uninformed conception that a scientific model expresses a copy of reality. Their most common argument was that a model is created from the results of experiments, observations of nature, theories, and laws.

In contrast, one-third of pre-service teachers (36%) believed that a scientific model does not express a copy of reality. Their most common argument was that models are created from scientists’ imaginations. Five out of 12 in-service teachers’ written responses also made similar arguments. Remarkably, 30.6% and 42.6% of the pre-service and in-service teachers were uncertain whether a scientific model expresses a copy of reality.

Pre-service and in-service science teachers’ conceptions of the NOS: Scientific method.

Nearly half of the pre-service and in-service science teachers (43.8% and 44.6%) held the uninformed conception of the scientific method. They believed that scientists must follow a fixed step-by-step method to obtain scientific knowledge. Three in-service teachers also confirmed that a fixed step-by-step scientific method is publicly presented in textbooks. Conversely, 30.4% and 41.6% of the pre-service and in-service teachers correctly stated that the scientific method could be reordered or that some steps could be removed.

The majority of pre-service teachers (39.1%) were uncertain whether science and the scientific method could provide answers for all questions, and the 49.5% of in-service teachers held the uninformed

Table 3: Pre-service and in-service science teachers’ conceptions of the NOS: Scientific method

Item	Uninformed (%)		Uncertain (%)		Informed (%)	
	Pre	In	Pre	In	Pre	In
Item 5: Scientific method	43.8	44.6	25.9	13.8	30.4	41.6
Item 6: Scientific explanation	24.6	49.5	39.1	30.3	36.4	20.2
Item 7: Scientific experiment	10.8	5.0	28.8	12.8	60.4	82.2

conception. Six of the sixteen in-service teachers that provided written responses argued that science and the scientific method can answer all questions, because they are causal, reasonable, and explainable, and an additional five teachers argued that science is true and provable.

Furthermore, two in-service teachers predicted that scientists will come up with the answers or explanations to difficult questions at some point in the future. Conversely, 36.4% and 20.2% of the pre-service and in-service teachers indicated that science and the scientific method are not able to answer all questions. One third of their written responses provided examples of issues that science cannot explain, such as ghosts, spirits, the devil, black magic, the supernatural, fortune-tellers, etc.

Most of the pre-service and in-service science teachers (60.4% and 82.2%) expressed the informed conception that scientific knowledge is not originated from experiments only. They raised many alternative methods of building scientific knowledge, including observation, seeking further information, and investigation.

Pre-service and in-service science teachers’ conceptions of the NOS: Scientists’ work.

Most pre-service and in-service science teachers (91.0% and 80%) believed in the roles of creativity and imagination in science. The pre-service teachers believed that scientists’ creativity and imagination is involved in creating scientific models (18.4%) and designing scientific experiments (14.5%). The in-service teachers believed that scientists’ creativity and imagination is involved in the discovery of new scientific

Table 4: Pre-service and in-service science teachers’ conceptions of the NOS: Scientists’ work

Item	Uninformed (%)		Uncertain (%)		Informed (%)	
	Pre	In	Pre	In	Pre	In
Item 10: Creativity and imagination in science	6.3	10.0	2.7	10.0	91.0	80.0
Item 11: Subjectivity in science	62.2	86.1	26.1	11.9	11.7	2.0

knowledge (34.8%) and the creation of novel inventions (21.7%). However, two in-service teachers asserted that scientists always employ the scientific method and never rely on creativity and imagination in developing scientific knowledge because that could distort the data.

The majority of pre-service and in-service science teachers (62.2% and 86.1%) regarded scientists as open-minded and unbiased. In 60% of their written responses, pre-service teachers indicated that they consider being open-minded and unbiased to be one of the most desirable characteristics of scientists and that this characteristic could potentially lead to success in scientific works. Only a few pre-service and in-service science teachers (6.3% and 10%) correctly stated that scientists, as human beings, are not absolutely open-minded and unavoidably possess some biases.

Pre-service and in-service science teachers’ conceptions of the NOS: Scientific enterprise.

The majority of the in-service science teachers (51.5%) held the uninformed conception that science and technology are identical, while 38.7% of the pre-service teachers were uncertain. The in-service teachers’ favourite argument was that technology is originated from science. One third of the pre-service and in-service teachers’ written responses also expressed the

uninformed conception, which is the idea that technology is applied science. Three patterns of the relationship between science and technology emerged from analysis of all of the pre-service teachers’ written responses: technology is originated from science (54.4%); science and technology interact with each other (28.9%); and science creates technology and technology develops science (2.2%). Similarly, in particular to the in-service teachers’ written responses, there were three patterns of relationship between science and technology: 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%). Conversely, 36% and 26.7% of the pre-service and in-service science teachers correctly stated that science and technology are different.

Most pre-service and in-service science teachers (74.8% and 96%) viewed scientific enterprise as a social, collaborative activity. Two in-service teachers explicitly stated that “science is an activity for all.” In the pre-service teachers’ view, collaboration in scientific works is beneficial for more clarified knowledge, multidisciplinary scientific research, and peer review. The in-service teachers also further articulated four advantages of collaborative scientific enterprise: deriving more quality data, gaining a variety of perspectives, enhancing opportunity to

Table 5: Pre-service and in-service science teachers' conceptions of the NOS: Scientific enterprise

Item	Uninformed (%)		Uncertain (%)		Informed (%)	
	Pre	In	Pre	In	Pre	In
Item 12: Science and technology	25.2	51.5	38.7	21.8	36.0	26.7
Item 13: Science as social enterprise	3.6	2.0	21.6	2.0	74.8	96.0
Item 14: Social, political, and cultural influences on science	10.8	13.0	25.2	13.0	64.0	74.0

succeed, and enhancing the credibility of studies.

The majority of pre-service and in-service science teachers (64% and 74%) believed that society, politics, and culture potentially affect the development of scientific knowledge. For example, 19.6% and 25% of the pre-service and in-service teachers' written responses mentioned that specific cultural or value frameworks embedded in some societies impede science advancement, and, specifically, some pre-service teachers indicated that religion could be an obstacle to scientific advancement. In addition, some pre-service and in-service teachers noted that political influence, such as a grant for scientific research, could affect scientific advancement in specific fields.

Pre-service and in-service science teachers' conceptions of the NOS: Holistic view.

During analysis of the pre-service and in-service teachers' responses, three types of patterns were noticed: a highly consistent pattern (Items 2, 3, 4, and 8), a consistent pattern (Items 1, 5, 7, 10, 11, 13, and 14), and a poorly consistent pattern (Items 6, 9, and 12). Items are shown in Figure 1 in the Appendix.

Discussion

The majority of pre-service and in-service science teachers in this study, like others around the world, held these uninformed conceptions of the NOS: (a) the laws-are-mature-theories-fables (Abd-El-Khalick, Bell, & Lederman, 1998; Abd-El-Khalick & BouJaoude, 1997; Dogan & Abd-El-Khalick, 2008; Haidar, 1999; Rubba & Harkness, 1993; Thye & Kwen, 2003); (b) theories are less secure than laws (Bell, Lederman, & Abd-El-Khalick, 2000; Ogunniyi, 1982); (c) the universal, step-wise scientific method, (Abd-El-Khalick & BouJaoude, 1997; Craven, Hand, & Prain, 2002; Dogan & Abd-El-Khalick, 2008; Haidar, 1999; Mellado, 1997; Murcia & Schibeci, 1999; Palmquist & Finley, 1997); (d) scientific knowledge is cumulative knowledge (Haidar, 1999; McComas, 1998); and (e) science is objective (Abd-El-Khalick & BouJaoude, 1997; Brickhouse, 1990; Dogan & Abd-El-Khalick, 2008; Gallagher, 1991; Haidar, 1999; Murcia & Schibeci, 1999; Promkatkeaw, Sungong, & Kaewviyudth, 2007; Rampal, 1992; Thye & Kwen, 2003). For them, the status of, and relationship between, theories and laws rely heavily on the availability of accumulative, supporting evidence. Scientific progress is seen as a cumulative process

rather than a revisionary process (Brickhouse, 1990; Haidar, 1999). The presentation of a fixed-step scientific method or verification-type laboratory activities in various school science textbooks contributes to these uninformed conceptions (Haidar, 1999; Palmquist & Finley, 1997), and this, unfortunately, leads some teachers to portray science as objective rather than subjective (Gallagher, 1991; Mellado, 1997). Objectivity, or being open-minded and unbiased, is also regarded as one of essential characteristics of a good, successful scientist (Palmquist & Finley, 1997).

However, the pre-service and in-service science teachers in this study widely held informed conceptions of the NOS regarding hypotheses and theories, such as the following: science as tentative (Bell, Lederman, & Abd-El-Khalick, 2000; Mellado, 1997; Palmquist & Finley, 1997); scientific experimentation; creativity and imagination in science (Abd-El-Khalick, Bell, & Lederman, 1998; Bell, Lederman, & Abd-El-Khalick, 2000; Murcia & Schibeci, 1999); science as social enterprise; and social, cultural, and political influences on science (Brush, 1989; Haidar, 1999; Mellado, 1997; Murcia & Schibeci, 1999; Rubba & Harkness, 1993; Tairab, 2001). They did not raise subjectivity or creativity as an important factor for tentative science, as noted by Bell, Lederman, and Ad-El-Khalick (2000). It was also found that the 'laws-are-mature-theories-fables' might lead teachers to mistakenly answer the tentativeness of science item correctly (Bell, Lederman, & Abd-El-Khalick, 2000; Thye & Kwen, 2003).

A high degree of uncertainty was indicated by the pre-service and

in-service teachers in this study with regard to the items relating to hypotheses and theories, including: theories are less secure than laws, scientific method, scientific explanation, scientific model, and science and technology. They raised many phenomena that science cannot explain (Lunn, 2002). These results were similar to findings by Tairab (2001) and Promkatkeaw et al. (2007) that show teachers dominantly view technology as applied science. The distinction between science and technology also appeared to be a difficult task (Rubba & Harkness, 1993). Therefore, a clear distinction and relationship between science and technology should be advocated.

Implications

Science teachers' conceptions of the NOS influence their actions in classrooms. Therefore, helping science teachers to acquire an adequate understanding of the NOS should be a basic requirement for science teacher preparation curriculum and science teacher professional development programmes. In the case of science teacher education, some pre-service teachers enter programmes with largely unexamined conceptions of the NOS, and, too often, leave without challenging these underdeveloped conceptions (O'Brien & Korth, 1991). This study revealed that, presently, a significant number of Thai pre-service and in-service science teachers need urgent help from involved stakeholders to remedy their uninformed conceptions of the NOS. Science teacher preparation curriculum and science teacher professional development programmes should address these uninformed conceptions.

The NOS should be explicitly mentioned and included in science teacher education curriculum and science teacher professional development programmes. It should not be assumed to be a side effect or secondary product of hands-on inquiry programmes (Akindehin, 1988). Empirical evidence (Akindehin, 1988; Billeh & Hassan, 1975; Carey & Strauss, 1968; King, 1991; Ogunniyi, 1982) indicates that explicit instruction about the NOS has the potential to improve science teachers' conceptions of the NOS. Examples of explicit teaching approaches include: writing assignments defining characteristics of science and pseudo-science (Craven, Hand, & Prain, 2002), explicit discussion of the NOS and its role in science teaching (Palmquist & Finley, 1997), small-group peer discussions and debates (Craven, Hand, & Prain, 2002), interviewing relative to students' alternative conceptions and designing inquiry activities for conceptual change (Tsai, 2006). However, explicitly teaching the NOS outside science content has only a limited effect on changing and improving science teachers' understanding of the NOS. Therefore, as Driver, Leach, Miller, and Scott (1996) suggested, NOS-associated activities and discussions should not be an add-on, but should be tightly linked to science content.

Science teachers' different views of science may arise from their views about how children learn; consequently, the constructivist epistemology should be included as one essential aspect of science teacher education curriculum and science teacher professional development programmes. Growing awareness of, and commitment to, constructivism

among science teachers has the potential to improve conceptions of the NOS, especially with regard to the tentativeness of science and theory-laden observation (Pomeroy, 1993).

The two-tier items (i.e. optional plus written responses) of the MOSQ demonstrate potential for improving the clarity with which respondents are able to articulate and characterise conceptions of the NOS, especially by means of a written response. However, because of the amount time needed to fill out the questionnaire and the need for large-scale implementation, in the further step, the researcher plans to revise the MOSQ to use multiple-choice items that maintain or strengthen the empirical focus. The revised MOSQ will consist of two main parts. The first part consists of 'agree or disagree' multiple-choice items, which are to be constructed from the written responses empirically derived from this study. The open-ended part of the revised MOSQ may appear as: "None of the above choices fits my viewpoint, I think that..." This revised MOSQ might be a more convenient method of exploring teachers' conceptions of the NOS that could be readily employed by science teacher professional development programmes and the results of which could be considered when developing science teacher preparation curriculum. Nonetheless, the present version of the MOSQ is useful to some extent in capturing science teachers' conceptions of the NOS, both quantitatively and qualitatively.

The final implication is to study the relationship between pre-service and in-service science teachers' conceptions of the NOS and their classroom practices in the Thai context. 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 pre-service and in-service science teachers in Thailand. Nonetheless, this study shows that there is a current need for improved nature of science teacher education for both new and established science teachers in Thailand.

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Appendix

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

Dr. Khajornsak Buaraphan is a lecturer at Institute for Innovative Learning, Mahidol University, 999 Salaya, Phuttamonthon, NaKhon Pathom, Thailand 73170. Correspondence concerning this article may be sent to ilkhajornsak@mahidol.ac.th.

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