Thai pre-service science teachers' conceptions of the nature of science

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Abstract

The conceptions of the nature of science (NOS), particularly scientific knowledge, scientific method, scientists' work, and scientific enterprise, of 113 Thai pre-service science teachers were was captured by the Myths of Science Questionnaire (MOSQ) in the first semester of the 2008 academic year. The data was quantitatively and qualitatively analysed. The results revealed that nine of the fourteen MOSQ items presented two consistent response patterns. Five were informed responses (i.e., hypotheses and theories, tentativeness of science, universal step-wise scientific method, science as experimental knowledge, creativity and imagination in science and science as social enterprise), while the other four were uninformed responses (i.e., theories and laws, science as cumulative knowledge, and theory-laden observation). The highest percentage of informed, uninformed and uncertain responses regarded the tentativeness of science, science as cumulative knowledge and the ability of science to answer all questions, respectively. The implications of preparing science teachers are also discussed.

Keywords: Pre-service science teacher, nature of science, Myth of Science Questionnaire, Thailand

Introduction

Science is an important subject at all levels of education. However, numerous studies have shown that many students, and even 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 weighting scientific evidence provided in legal proceeding[s]. 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) is established as one of the desirable characteristics of a scientifically literate person. An scientifically literate person refers to someone 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).

Therefore, many science curricula now aim to help learners attain an adequate understanding of the NOS or an understanding of "science as a way of knowing" (American Association for the Advancement of Science, 1989, p.1). There are various advantages of inclusion of the NOS in science curricula. Driver, Leach, Miller, and Scott (1996) have suggested five arguments in support of the inclusion of the NOS as a goal of science instruction, i.e., 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 Thai National Education Act B.E. 2542 (1999) and Amendments (Second National Education Act B.E. 2545 (2002) (Office of the Education Council, 2002), brings all stakeholders together in continuing joint efforts toward education reform. Science is emphasised 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 had 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 definite the period of investigation, (and) understand that science, technology and [the] 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). Teachers 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 about 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 the NOS encompasses various fields, especially epistemology, which involves 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).

In addition, from an analysis of eight international science standard documents, those authors summarised a consensus view of the NOS. Some aspects of the NOS include: 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 each other; and scientific ideas are affected by their social and historical milieu (McComas, Clough et al., 1998, pp. 6-7).

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

Most pre-service science teachers hold mixed views about the NOS. Some of them are traditional, naïve, or uninformed, while others are contemporary or informed. The studies related to conceptions of the NOS held by pre-service science teachers can be categorised in four major groups: scientific knowledge, scientific method, scientists' work, and scientific enterprise.

Scientific knowledge: Hypotheses, theories and laws

Regarding the relationship between hypotheses and theories, nearly half of the pre-service teachers surveyed in Thye and Kwen (2003) believed that a "scientific theory is a hypothesis that has not been proven yet" (p. 6). After being empirically tested, nearly all pre-service teachers stated that a hypothesis becomes a theory (Haidar, 1999).

Laws are statements or descriptions of discernible patterns developed to account for observable phenomena, while theories are inferred explanations for those phenomena. These two types of knowledge play different roles in science. However, many pre-service science teachers cannot distinguish between them. The most popular uninformed view about theories and laws for most of them is the "laws-are-mature-theories-fable" (Thye & Kwen, 2003). That is, many pre-service teachers believe that when enough supporting evidence is accumulated, theories become laws (Abd-El-Khalick, Bell, & Lederman, 1998). The common subsequent effect of the "laws-are-mature-theories-fable" is the misbelief that laws are less tentative than theories (Bell, Lederman, & Abd-El-Khalick, 2000).

Some prospective science teachers strongly believe in a simplistic hierarchical relationship between hypotheses, theories, and laws. For example, 73.1% of pre-service science teachers in Rubba and Harknes study (1993) had naïve conceptions that, "a hypothesis is tested by experiments. If it proves to be correct, it becomes a theory. After the theory has been proven many times by different people and has been around a long time, it becomes a law" (p. 418). It also leads to the favourite assertion about the credibility of hypotheses, theories, and laws, i.e., "theories are general propositions which are more credible than hypotheses but less credible than laws" (Ogunniyi, 1982, p. 28).

Scientific knowledge: Tentativeness of science

Regarding the status of scientific knowledge, we can categorise pre-service science teachers into two groups using a static-dynamic split. The pre-service teachers in the first group view science as stable or having static status (Craven, Hand, & Prain, 2002; Murcia & Schibeci, 1999; Tairab, 2001), while those in the second group view science as tentative or having a dynamic status (Bell et al., 2000; Mellado, 1997; Palmquist & Finley, 1997). In the static-science group, student teachers claimed that science is a collection of facts or a body of knowledge that explains the world with little or no elaboration. The purpose of scientific research, therefore, is to collect as much data as possible (Craven et al., 2002; Tairab, 2001). The student teachers belonging to this group appeared to have minimal awareness of the tentative nature of scientific knowledge (Murcia & Schibeci, 1999). In the dynamic-science group, the student teachers generally viewed subjectivity and creativity as the important factors contributing to the tentative nature of science (Abd-El-Khalick et al., 1998).

Scientific knowledge: Cumulative knowledge

The belief of scientific knowledge as cumulative knowledge is commonly held by pre-service teachers. In Haidar's (1999) study, 48% of pre-service science teachers believed that scientific knowledge is cumulative and its advancement strongly depends on increasing observation.

Scientific knowledge: Scientific model

Many pre-service science teachers, especially those who hold the constructivist view, can articulate the role of scientific models as representations, rather than exact replicas, of experienced phenomena (Bell et al., 2000). A scientific model, for them, is seen not as a copy of reality, but as scientists' best ideas or educated guesses to represent reality (Haidar, 1999). However, the appearance of scientific models in various public media, especially science textbooks, persuades most prospective science teachers to think about scientific models as a copy of reality. For example, in Thye and Kwen's research (2003), 42% of pre-service teachers were not aware of the limitations of the scientific model. They asserted that, "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). In addition, 70% of prospective teachers in Ogunniyi's study (1982) firmly believed that molecules, atoms, and electrons are empirical concepts. The example of the atomic model is frequently raised to support the conception of the scientific model as a copy of reality.

Scientific method: Universal, step-wise method

The scientific method is commonly perceived by pre-service science teachers as "a universally applicable, lock-step procedure" (Craven et al., 2002, p. 791). The percentage of pre-service science teachers who believe in a universal, step-wise scientific method varies from study to study, for example 23.5% (Murcia & Schibeci, 1999), to 33% (Craven et al., 2002), to 60% (Palmquist & Finley, 1997), to 65% (Haidar, 1999), and even to 100% (Mellado, 1997) of respondents. The main argument supporting a universal, step-wise scientific method is that its ordered, rigid stages lead to objectivity of scientific work and, finally, valid scientific claims (Mellado, 1997; Palmquist & Finley, 1997). Accordingly, the best scientists are defined as those who follow the steps of the scientific method (Haidar, 1999). Some pre-service teachers, however, did not believe in a universal step-wise scientific method (Mellado, 1997). They did not believe that “there are fixed steps that scientists always follow to lead them without fail to scientific knowledge” (Murcia & Schibeci, 1999, p. 1134).

Scientific method: Experiment

Some pre-service teachers raised experimentation as a necessary means to claim the validity of scientific knowledge. Thye and Kwen (2003) found that 79% of pre-service teachers expressed an uninformed view about scientific knowledge as experimental knowledge. They argued 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" (p. 5).

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 student teachers, subjectivity plays a major role in the development of scientific ideas (Palmquist & Finley, 1997). Subjectivity, which involves the individuality of scientists, e.g., their personalities, background, motivations, and beliefs, can affect scientists in selecting, interpreting, recording, and reporting evidence (Abd-El-Khalick et al., 1998; Murcia & Schibeci, 1999) and, eventually, generating conclusions or theories (Abd-El-Khalick et al., 1998; Thye & Kwen, 2003). For example, 46% of pre-service teachers in Thye and Kwen’s research (2003) believed that “the same piece of evidence or the same set of data can be subject to multiple interpretations" (p. 7).

However, many pre-service teachers strongly believed in objectivity in science, which is firmly based upon theory-free or value-free observation. For example, 40% of pre-service elementary teachers claimed that the validity of scientific knowledge originates from objective and value-free observation (Murcia & Schibeci, 1999). That is, scientists must be objective in their work (Palmquist & Finley, 1997), and observation should not be influenced by the theories they hold (Haidar, 1999). Objectivity is consequently proposed as one of the desirable characteristics of scientists. One of the four case studies in Mellado’s (1997) study, Ana, said that, “universal, objective criteria to exist, although extrascientific factors are at time involved…thence arriving at theories which are a true reflection of reality” (p. 343).

Scientists’ work: Creativity and imagination in science

The role of creativity and imagination in the construction of scientific ideas is acknowledged by most pre-service science teachers (Abd-El-Khalick et al., 1998; Bell et al., 2000). Creativity and imagination are thought to be mainly involved in designing research or experimental procedures, generating new ideas, and developing technology (Murcia & Schibeci, 1999). Creativity-related science leads most student teachers to “dismiss the view of science as a completely objective and rational activity” (Bell et al., 2000, p. 570). However, some pre-service teachers deny the role of creativity and imagination in science. In Murcia and Schibeci (1999), nearly 10% of pre-service teachers expressed the belief that, “science was fact or truth and creativity did not have a place" (p. 1132). Also, in Thye and Kwen (2003), 33% of pre-service teachers did not seem to think that creativity and imagination were required as steps of scientific investigation. 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 explicitly recognised by most pre-service science teachers (Haidar, 1999; Mellado, 1997; Murcia & Schibeci, 1999; Rubba & Harkness, 1993; Tairab, 2001). The literature revealed two types of cultural influences. The first comes from the larger society, while the other comes from the culture of science itself, including the influences of professional organisations, funding sources and peer review (Bell et al., 2000, p. 570). Research funding is seen as an important factor. In one study, 75.5% of pre-service elementary teachers believed that "the bodies [government departments] that supply the money for research influence the direction of science" (Murcia & Schibeci, 1999, p. 1135). However, the influences of social and cultural factors on scientific practice are sometimes overlooked by pre-service teachers (Abd-El-Khalick et al., 1998). Many of them neglected science as a social enterprise or a form of human cultural activity (Tairab, 2001).

Scientific Enterprise: Interaction between science and technology

It is, maybe, an easy task for pre-service teachers to recognise the interaction between science and technology, such as the ideas that science is the knowledge base for technology and technology influences scientific advancement (Rubba & Harkness, 1993). However, distinguishing between science and technology is probably a very difficult task for them (Rubba & Harkness, 1993). The commonplace naïve conception about science and technology is that technology is applied science (Tairab, 2001).

Thai pre-service science teachers' conceptions of the nature of science

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 northeast region. A few of these studies dealt with pre-service teachers. Of the 26 Master's theses that examined teachers' conceptions of the NOS, there were only three studies related to pre-service teachers' conceptions of the NOS, one dealing with pre-service teachers in general (Wansudol, 2000) and two others dealing specifically with pre-service science teachers (Jongchidklang, 2000; Phiankaew, 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 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. Five major findings emerged from these studies.

First, pre-service teachers generally demonstrated a high level of understanding of the NOS (Jongchidklang, 2000; Phiankaew, 1999; Wansudol, 2000). There were only a few subscales on which most student teachers showed a moderate level of understanding, i.e., the Parsimony subscale (Jongchidklang, 2000; Wansudol, 2000) and the Consistency subscale (Jongchidklang, 2000; Phiankaew, 1999; Wansudol, 2000).

Second, in general, male and female pre-service teachers did not show different understandings of the NOS (Jongchidklang, 2000; Phiankaew, 1999; Wansudol, 2000). However, on the Consistency and Causality subscales, males held significantly more understanding of the NOS than females (Jongchidklang, 2000), but they showed less understanding of the Amoral subscale than females (Phiankaew, 1999).

Third, pre-service teachers with different content backgrounds showed different levels of understanding of the NOS. In general, comparing with pre-service chemistry, general science, and physics teachers, pre-service biology teachers expressed more understanding of the NOS in particular to its interaction between science, technology and society, creativity and testable aspects (Phiankaew, 1999).

Fourth, pre-service science teachers held a significantly better understanding of the NOS than pre-service elementary teachers on two scales, i.e., the assumptions of the nature and interaction between science-society-technology scales (Jongchidklang, 2000).

Finally, statistical interactions between the variables of gender and learning programme on the understanding of the NOS, in general, were not found to be significant (Wansudol, 2000).

This study aimed to explore conceptions of the NOS held by Thai pre-service science teachers in a more qualitative manner. The findings of this study may contribute to the relatively limited literature on pre-service science teachers' conceptions of the NOS and initially inform involved stakeholders of the current state of pre-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 pre-service level.

Research Question

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

Methods

Instrument

To explore pre-service science teachers' conceptions of the NOS, the authors of this study utilised a newly developed instrument entitled the Myths of Science Questionnaire (MOSQ). The MOSQ consists of 14 items and addresses four aspects of the NOS: (1) scientific knowledge (6 items—Items 1, 2, 3, 4, 8, 9); (2) scientific method (3 items—Items 5, 6, 7); (3)

scientists' work (2 items—Items 10, 11); and (4) scientific enterprise (3 items—Items 12, 13, 14). The creation of the MOSQ items was largely inspired by McComas's (1998) article entitled "The Principal Elements of the Nature of Science: Dispelling the Myths." All of the MOSQ items are presented as Figure 1 in the Appendix. 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 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 science teachers at one university 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 was collected during the first semester of the 2008 academic year. 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. The researchers administered the MOSQ and collected it back from all of the respondents. A majority of the respondents (83.2%) were female. There were 28 (24.8%) pre-service science teachers in their first year of the study, and 17 (15.0%), 24 (21.2%), 20 (17.7%), 24 (21.2%) in the second, third, fourth and fifth years of study, respectively. The major fields of study of the participants were biology (33.3%), chemistry (30.7%), general science (20.0%) and physics (16.0%). Notably, the first year pre-service science teachers had not yet selected a major field of study.

Data analysis

The frequency of each response (i.e., agree, uncertain, and disagree) was first counted, and subsequently calculated for its 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 their frequencies calculated for each category.

Results

Pre-service science teachers' conceptions of the NOS: Scientific knowledge

The pre-service science teachers' conceptions of the NOS regarding scientific knowledge are shown in Table I.

Table I *Pre-service science teachers' conceptions of the NOS: Scientific knowledge*

Item No.	Response	Number of respondents				
		1st year	2nd year	3rd year	4th year	5th year
1	Agree	6	1	3	1	2
	Uncertain	10	5	9	9	4
	Disagree	11	11	12	10	18
2	Agree	12	9	11	7	10
	Uncertain	6	3	11	4	10
	Disagree	9	5	2	9	4
3	Agree	19	14	18	20	19
	Uncertain	8	2	5	0	3
	Disagree	0	1	1	0	2
4	Agree	1	0	0	1	0
	Uncertain	3	0	1	1	0
	Disagree	23	17	23	18	24
8	Agree	21	12	21	16	20
	Uncertain	4	3	3	3	4
	Disagree	1	2	0	1	0
9	Agree	14	7	5	5	6
	Uncertain	10	6	6	3	9
	Disagree	2	4	13	12	9

A majority of pre-service science teachers (55.4%) held the contemporary view about hypotheses and theories. They disagreed with the statement "hypotheses are developed to become theories only." Of written responses, 44.2% argued that hypotheses are potentially developed to become laws, and 13% of written responses additionally argued that hypotheses may be proven to be false. However, one-third of pre-service science teachers were uncertain about hypotheses and theories, while only three of them explicitly expressed an informed conception. Interestingly, the fifth year pre-service science teachers held markedly more informed conceptions of hypotheses and theories than the others.

Nearly one third of pre-service science teachers (30.36%) were uncertain about theories and laws. In addition, 43.8% of respondents expressed the traditional view that scientific theories are less secure than laws. A major explanation supporting the uninformed view (29.2%) was that, "theories are less credible than laws because theories can be changed, but laws are fixed, they cannot be changed." Only five student teachers explicitly demonstrated informed conception by stating that "theories and laws are equally credible."

A very high proportion of pre-service science teachers (80.4%) believed in "laws-are-mature-theories-fables." A majority of the written responses provided to support their view (70%) stated that "when the theories have been proved, they can be developed to become laws."

All pre-service science teachers, except one who was uncertain, expressed the contemporary view about the tentativeness of science. Nearly all of the written responses (94.4%) raised the discovery of new or more credible evidence as a reason why scientific knowledge can be changed. However, one teacher believed that "theories can be developed to become law, thus scientific knowledge is tentative." This response demonstrates the conjunction of two beliefs—the first one is incorrect, but accidentally leads to another correct one.

A majority of respondents (81.1%) 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). The majority of written responses (59.5%) supporting this naïve view indicated that "the accumulation of evidence increases the credibility of scientific knowledge."

The scientific model item revealed a good split of answers among naïve, informed and uncertain views. We found that 33.3% of pre-service science teachers agreed with the statement "a scientific model expresses a copy of reality," while 36.0% disagreed, and 30.6% were uncertain. A major pattern of reasoning (33.8%) supporting the disagree response was "the scientific model does not express a copy of reality because it is created from scientists' imaginations." Notably, the first year pre-service science teachers were highly uncertain and held an uninformed conception of scientific models.

Pre-service science teachers' conceptions of the NOS: Scientific method

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

***Table II** Pre-service science teachers' conceptions of the NOS: Scientific method*

Item No.	Response	Number of respondents				
		1st year	2nd year	3rd year	4th year	5th year
5	Agree	12	8	8	10	11
	Uncertain	9	5	2	6	7
	Disagree	6	4	14	4	6
6	Agree	6	7	3	5	6
	Uncertain	10	4	5	15	9
	Disagree	10	6	15	0	9
7	Agree	5	3	1	3	0
	Uncertain	6	2	4	17	3
	Disagree	15	12	19	0	21

An uninformed conception of the scientific method was reported by 43.8% of pre-service science teachers. They believed that scientists must follow a fixed step-by-step method to obtain scientific knowledge. Interestingly, nearly one third of respondents (30.4%) were uncertain about whether the stages of the scientific method could be reordered or if any could be removed. Remarkably, the third year pre-service science teachers held informed conceptions of the scientific method.

More than one third (39.1%) of pre-service teachers were uncertain about whether "science and scientific method can answer all questions," and more than one third (36.4%) of them disagreed with the statement. Of 90 written responses, 60 of them (66.7%) raised issues (e.g., ghosts, spirits, the devil, black magic, the supernatural, fortune-tellers, etc.) that science can not explain. Interestingly, three responses raised the issue of time, i.e., eventually scientists will come up with explanations of such things. Notably, the fourth year pre-service science teachers were highly uncertain, and all of them had uninformed conceptions regarding this item.

The contemporary view that "scientific knowledge is not originated from experiments only" was expressed by 60.4% of respondents. 30 of the 87 written statements (34.5%) supported their responses by stating that scientific knowledge can be obtained from observation. Furthermore, 20 of the 87 written responses (23.0%) indicated that more than one method can be used to seek scientific knowledge. Again, the fourth year pre-service science teachers were highly uncertain, and all of them held naïve views with respect to this item.

Pre-service science teachers' conceptions of the NOS: Scientists' work

The pre-service science teachers' conceptions of the NOS with respect to scientists' work are depicted in Table III.

Table III *Pre-service science teachers' conceptions of the NOS: Scientists' work*

Item No.	Response	Number of respondents				
		1st year	2nd year	3rd year	4th year	5th year
10	Agree	6	0	0	0	1
	Uncertain	1	1	1	0	0
	Disagree	19	16	23	20	23
11	Agree	16	11	14	11	17
	Uncertain	9	5	3	6	6
	Disagree	1	1	7	3	1

Nearly all pre-service science teachers (91.0%) believed that "scientists use creativity and imagination in developing scientific knowledge." The two frequently raised examples were the creativity and imagination involved in creating scientific models (18.4%) and designing scientific experiments (14.5%).

Nearly two thirds of pre-service science teachers (62.2%) agreed that "scientists are open-minded without any biases." The majority of written responses (60%) stated that being open-minded and unbiased are desirable characteristics of scientists that allow them to succeed in their work. Only 11.7% of respondents held the contemporary view and argued that some scientists are not open-minded and possess some biases.

Pre-service science teachers' conceptions of the NOS: Scientific enterprise

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

***Table IV** Pre-service science teachers' conceptions of the NOS: Scientific enterprise*

Item No.	Response	Number of respondents				
		1st year	2nd year	3rd year	4th year	5th year
12	Agree	13	5	5	2	3
	Uncertain	9	7	2	18	7
	Disagree	4	5	17	0	14
13	Agree	2	0	0	2	0
	Uncertain	1	0	1	18	4
	Disagree	23	17	23	0	20
14	Agree	8	1	0	3	0
	Uncertain	7	0	3	17	1
	Disagree	11	16	21	0	23

More than one third of pre-service science teachers (36%) disagreed with the statement, "science and technology are identical." One third of written responses expressed the pre-service science teachers' naïve conceptions that "technology is applied science." Three patterns of the relationship between science and technology emerged from the responses, i.e., technology originated from science (54.4%), science and technology interact with each other (28.9%) and science creates technology and technology develops science (2.2%). Notably, the fourth year pre-service science teachers were highly uncertain, and none of them held informed conceptions of the interaction between science and technology.

A majority of pre-service science teachers (74.8%) disagreed with the item "scientific enterprise is an individual enterprise." Nearly all of the written responses (97.8%) claimed that science is a social activity that involves many persons. The fourth year pre-service science teachers were highly uncertain, and none of them held informed conceptions regarding science as a social activity.

Nearly two thirds of pre-service science teachers (64%) believed that society, politics and culture potentially affect the development of scientific knowledge in some ways. Again, the fourth year pre-service science teachers were highly uncertain, and none of them possessed contemporary views regarding this item.

Discussion

Most of the pre-service science teachers in this study, like other pre-service teachers around the world, held uninformed conceptions about the roles of hypotheses, theories, and laws, particularly the "laws-are-mature-theories-fables" (Abd-El-Khalick et al., 1998; Rubba & Harkness, 1993; Thye & Kwen, 2003) that lead them to perceive theories as less secure than laws (Ogunniyi, 1982).

The tentativeness of science or dynamic of science is highly recognised by pre-service science teachers (Abd-El-Khalick et al., 1998; Bell et al., 2000; Craven et al., 2002; Mellado, 1997; Murcia & Schibeci, 1999; Palmquist & Finley, 1997). However, they did not raise subjectivity or creativity as important factors that make science tentative, like Bell, Lederman, and Abd-El-Khalic (2000) noticed, but instead raised the discovery of new credible evidence. The caution before making judgments about pre-service 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 et al., 2000; Thye & Kwen, 2003).

Scientific progress can be best described as a revisionary process rather than a cumulative process (Brickhouse, 1990). However, a majority of pre-service science teachers in this study, similar to that of Haidar (1999), strongly believed in Baconian induction. They viewed science as cumulative knowledge, i.e., individual pieces of evidence are collected and examined until a law is discovered or a theory is invented. They were not aware of the problem of induction, i.e., "even a preponderance of evidence does not guarantee the production of valid knowledge" (McComas, 1998, p. 58).

Pre-service science teachers who believed that a scientific model is not a copy of reality, similar to Haidar (1999) and Bell, Lederman, and Abd-El-Khalick (2000), believed this because a model is created from scientists' imaginations as an educated guess. Other pre-service teachers believed that a scientific model is a copy of reality, which is similar to the findings of Ogunniyi (1982) and Thye and Kwen (2003).

The pre-service science teachers in this study were highly uninformed and uncertain about the scientific method. They strongly believed in the universal, step-wise scientific method, which is widely propagated in school science textbooks (Craven et al., 2002; Haidar, 1999; Mellado, 1997; Murcia & Schibeci, 1999; Palmquist & Finley, 1997). Also, the form of cookbook or verification-type laboratory activities, unfortunately, leads student teachers to portray science as a rigid procedural investigation leading to reliable, valid and dependable knowledge (Palmquist & Finley, 1997). In this study, the fixed process of the scientific method is also linked with the objectivity of scientific knowledge (Gallagher, 1991; Mellado, 1997), but is not linked with the character of scientists as in Haidar's (1999) study. The term "scientific method" itself is, maybe, an issue. Abd-El-Khalick and BouJaoude (1997) found that without explicitly stating the term "scientific method," almost all teachers (94%) in their study adopted the more informed view that science activities are not completely logical and sequential.

Many pre-service science teachers neither believed nor were uncertain whether science and the scientific method can answer all questions. They raised questions about many phenomena that are unexplainable by science. In this group, some student teachers considered time as a major factor, predicting that at some point in the future, scientists will come up with explanations for these phenomena. More than half of pre-service science teachers believed that scientific knowledge is not solely originated from experiments. They frequently brought up observation and other methods of knowledge accumulation (Thye & Kwen, 2003).

Creativity and imagination were highly regarded as important in developing scientific knowledge, in particular to creating scientific models and designing experiments (Abd-El-Khalick et al., 1998; Bell et al., 2000; Murcia & Schibeci, 1999). A minority of pre-service science teachers believed in objectivity in science (Murcia & Schibeci, 1999; Thye & Kwen, 2003), and also raised it as an important characteristic of scientists, as in (Palmquist & Finley, 1997), in order to be successful in their work.

The idea that technology is an applied science is dominant among pre-service science teachers in this study. They cannot easily distinguish between science and technology (Rubba & Harkness, 1993). This finding has strong cultural roots because people tend to "point to artefacts and systems that followed scientific discoveries," e.g., 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). Three patterns of relationships between science and technology emerged in this study. One of them is similar to that described by Rubba and Harkness (1993), i.e., science interacts with technology. A majority of pre-service science teachers believed in science as a social activity, which is greatly influenced by society, culture and politics (Bell et al., 2000; Haidar, 1999; Mellado, 1997; Murcia & Schibeci, 1999; Rubba & Harkness, 1993; Tairab, 2001). Only a few prospective teachers did not perceive the influences of society, culture and politics on science advancement (Tairab, 2001).

Implications

Science teachers' conceptions of the NOS potentially influence their actions in classrooms. Therefore, preparing pre-service science teachers to acquire an adequate understanding of the NOS should be a basic requirement for teacher preparation programmes. However, the reality is that some pre-service science teachers arrive with largely unexamined conceptions of the NOS, and, too often, they leave the teacher education programmes without these conceptions being challenged (O'Brien & Korth, 1991). The MOSQ employed in this study may be useful for science teacher preparation programs in exploring pre-service science teachers' conceptions of the NOS at the beginning and the end of individual courses, or even the program as a whole. It is able to provide both quantitative and qualitative data of conceptions of the NOS.

If one accepts the importance of understanding the NOS, then pre-service science teacher education programs are obligated to develop new science teachers who understand a contemporary view of the NOS and its application to teaching (Palmquist & Finley, 1997, p. 596). The NOS should not be anticipated as a side effect or secondary product of hands-on inquiry (Akindehin, 1988); rather, it should be explicitly mentioned and included in science teacher education programmes. Based on empirical evidence (Akindehin, 1988; Billeh & Hassan, 1975; Carey & Strauss, 1968; King, 1991; Ogunniyi, 1982), explicit instruction on the NOS in science teacher education programmes has the potential to improve pre-service science teachers' conceptions of the NOS. However, explicitly teaching the NOS outside a science context has only a limited effect on changing and improving 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 et al., 1996).

Science teachers’ views about how student learn science potentially influence their views of science. Another aspect that should be included in science teacher education programmes is constructivist epistemology. Growing awareness of and commitment to constructivism among prospective science teachers have the potential to improve their conceptions of the NOS (Pomeroy, 1993), in particular as related to the tentativeness of science and theory-laden observation. The other implication is to study the relationship between pre-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. However, 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 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	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
2. Scientific theories are less secure than laws	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
3.Scientific theories can be developed to become laws	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
4. Scientific knowledge cannot be changed	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
5. The scientific method is a fixed step-by-step process	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
6. Science and the scientific method can answer all questions	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
7. Scientific knowledge comes from experiments only	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
8. Accumulation of evidence makes scientific knowledge more stable	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
9. A scientific model (e.g., the atomic model) expresses a copy of reality	☐ Agree ☐ Uncertain ☐ Disagree ……………………………………..
10. Scientists do not use creativity and imagination in developing scientific knowledge	☐ Agree ☐ Uncertain ☐ Disagree

	……………………………………..
11. Scientists are open-minded without any biases	☐ Agree ☐ Uncertain ☐ Disagree
	……………………………………..
12. Science and technology are identical	☐ Agree ☐ Uncertain ☐ Disagree
	……………………………………..
13. Scientific enterprise is an individual enterprise	☐ Agree ☐ Uncertain ☐ Disagree
	……………………………………..
14. Society, politics, and culture do not affect the development of scientific knowledge	☐ Agree ☐ Uncertain ☐ Disagree
	……………………………………..

Figure 2

Pre-service science teachers' conceptions of the nature of science (Items 1 to 7)

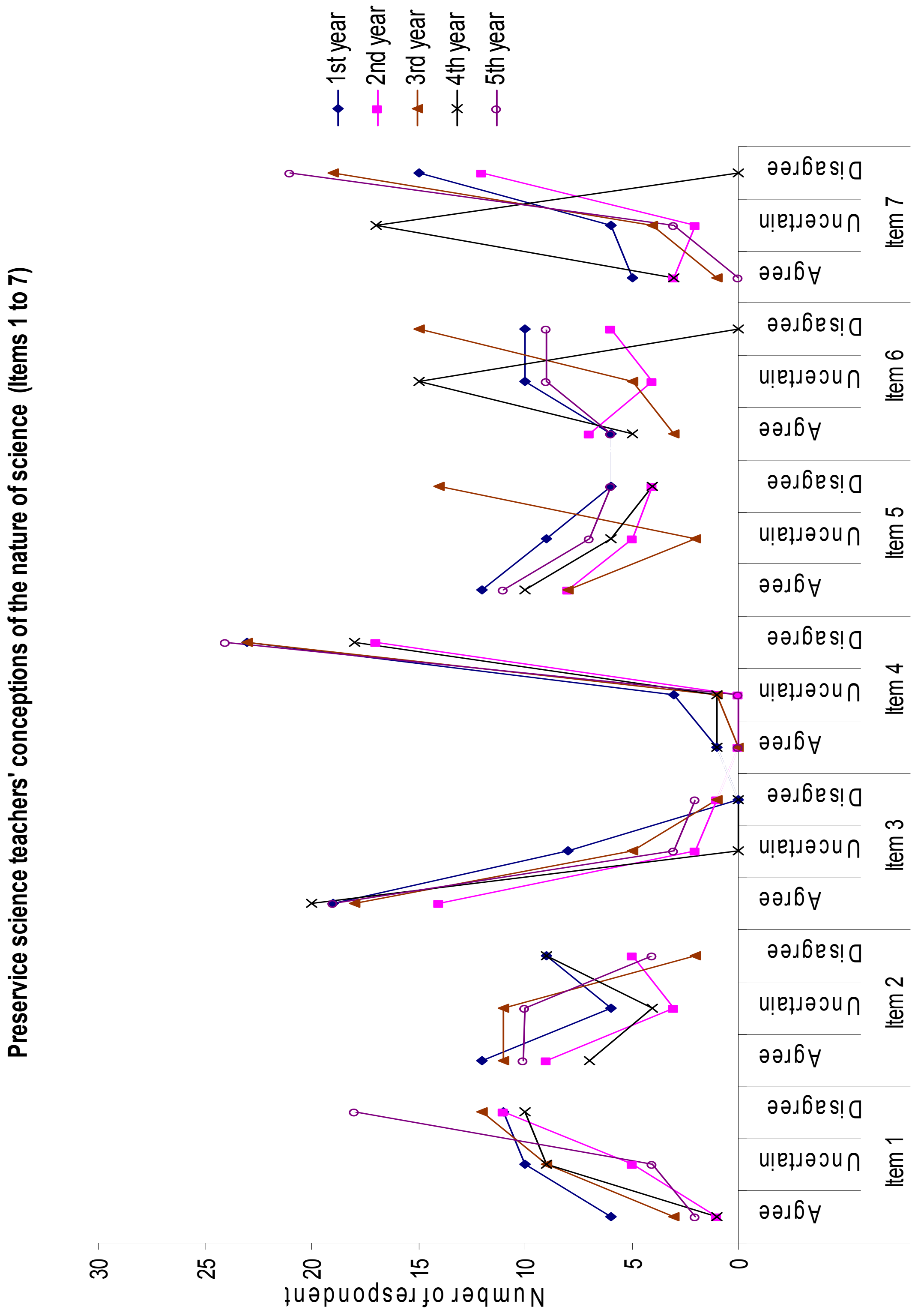

Figure 3

Pre-service science teachers' conceptions of the nature of science (Items 8 to 14)