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Pre-service Physics Teachers' Conceptions of Nature of Science

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Understanding of NOS (nature of science) appears as a prerequisite of a scientifically literate person. Promoting adequate understanding of NOS in pre-service physics teachers is, therefore, an important task of science educators. Before doing that, science educators must have information concerning their pre-service teachers' conceptions of NOS. This study used the MOSQ (myths of science questionnaire) to explore 17 pre-service physics teachers' conceptions of NOS. Commonly, these pre-service teachers expressed misunderstandings about NOS with respect to: (1) the relationship between theory and law; (2) science as cumulative; (3) subjectivity in science; (4) the scientific method; and (5) the relationship between science and technology. Science educators should consider and utilize these common misunderstandings as a basis of curricular framework for further improving pre-service physics teachers' understanding of NOS.

Keywords: nature of science, pre-service physics teacher, physics education, science literacy, Thailand

Introduction

An understanding of NOS (nature of science) is 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 importantly… an understanding of nature of science" (Abd-El-Khalick & BouJaoude, 1997, p. 673). Therefore, many science curricula now aim to help learners attain an adequate understanding of NOS. There are various advantages of inclusion of the NOS in science curricula. That is, NOS enhances learning of science content, understanding of science, interest in science, decision-making in science-related issues, and science instructional delivery (Driver, Leach, Miller, & Scott, 1996).

In the Thai context, the proclamation of National Education Act B.E. 2542 (1999) and Amendments (Second National Education Act B.E. 2545 (2002)) (Office of the Education Council, 2002) bring all stakeholders together in continuing joint efforts toward national education reform. Science is emphasized in Section 23 of the Act. To support the reform, the Ministry of Education had launched a new curriculum, the Basic Education Curriculum (Ministry of Education, 2001), in which science is included in one of the eight learning strands. In the Science Learning Strand, the NOS is explicitly emphasized in the Learning Sub-strand 8: The Nature of Science and Technology, which consists of one standard (Standard Sc 8.1):

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> 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 with their students (Lederman, 1992). In particular to NOS, teachers' thorough understanding of NOS appears as a prerequisite of success in cultivating understanding of NOS in students they taught (Abd-El-Khalick & Lederman, 2000). An adequate understanding of NOS allows teachers to model appropriate science-related behaviors and attitudes (Murcia & Schibeci, 1999) that strongly influence students' views about NOS (Palmquist & Finley, 1997). As Lederman (1992) pointed out, the most important variables that influence students' beliefs about NOS are those specific instructional behaviors, activities and decisions implemented within the context of a lesson. 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). In the case of pre-service science teachers, one of the major responsibilities of teacher educators is, inevitably, to help pre-service teachers attain an adequate understanding of NOS, which subsequently serves them for future teaching. However, the extant studies have shown that pre-service science teachers possess an inadequate understanding of NOS. This situation might be harmful to Thailand in cultivating learners to become scientifically literate citizen for living in the future rapidly-growing scientific and technological world.

Literature Review

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 et al. (1998) provided 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 endeavors. (p. 4)

In addition, from an analysis of eight international science standard documents, those authors summarized a consensus view of the NOS. Some aspects of the NOS include: (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; (5) Observations are theory-laden; (6) Scientists are creative; (7) Science and technology impact each other; and (8) Scientific ideas are affected by their social and historical milieu (McComas et al., 1998, pp. 6-7).

Pre-service Science Teachers' Conceptions of NOS

From literature review, the author did not find the study specifically related to pre-service physics teachers' understanding of NOS, but found some related to pre-service science teachers. These studies showed that most pre-service science teachers hold mixed views about NOS, some of which were traditional or uninformed, while others were contemporary or informed. Four main categorized of pre-service science teachers' understanding of NOS emerged from the review: scientific knowledge, scientific method, scientists' work and scientific enterprise.

Scientific knowledge. Many pre-service teachers misunderstood the relationship between hypotheses, theories and laws. They believed that scientific theory is a hypothesis that has not been proven yet, but after being empirically tested, the hypothesis becomes a theory (Haidar, 1999; Thye & Kwen, 2003). Some pre-service teachers believed that when enough supporting evidence is accumulated, theories become laws (Abd-El-Khalick, Bell, & Lederman, 1998). Consequently, laws are less tentative than theories (Bell, Lederman, & Abd-El-Khalick, 2000). In addition, many pre-service teachers strongly believed a simplistic hierarchical relationship between hypotheses, theories and laws: 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 (Rubba & Harkness, 1993). This belief may lead teachers to perceive that theories are general propositions being more credible than hypotheses but less credible than laws (Ogunniyi, 1982).

Regarding the status of scientific knowledge, many student teachers believed 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 investigations is, therefore, to collect as much data as possible (Craven, Hand, & Prain, 2002; Tairab, 2001). Scientific knowledge is seen as cumulative knowledge and its advancement strongly depends on increasing observation (Haidar, 1999). These teachers appeared to have minimal awareness of the tentative nature of scientific knowledge (Murcia & Schibeci, 1999). On the contrary, some student teachers viewed science as tentative and generally raised subjectivity and creativity as the important factors contributing to the tentative nature of science (Abd-El-Khalick et al., 1998).

Many pre-service teachers are not aware of the limitations of scientific models. They think about a scientific model as a copy of reality. One main reason supported this belief is such model comes from scientific experiment and scientists publicly present it in textbooks and reference books (Ogunniyi, 1982; Thye & Kwen, 2003). Conversely, some pre-service 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 as scientists' best ideas or educated guesses to represent reality (Haidar, 1999).

Scientific method. Many pre-service teachers perceived the scientific method as a universally applicable, lock-step procedure (Craven et al., 2002; Haidar, 1999; Mellado, 1997; Murcia & Schibeci, 1999; Palmquist & Finley, 1997). They argued that the ordered, rigid stages of the scientific method lead to objectivity of scientific work, and finally, valid scientific claims (Mellado, 1997; Palmquist & Finley, 1997). Accordingly, good scientists are those who follow the steps of the scientific method (Haidar, 1999). Some pre-service teachers, however, disagreed with a universal step-wise scientific method. They did not believe that there are fixed steps that scientists always follow to prevent failing to scientific knowledge (Mellado, 1997; Murcia & Schibeci, 1999). Specifically, some pre-service teachers raised experimentation as a necessary means to claim the validity of scientific knowledge (Thye & Kwen, 2003). 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.

Scientists' work. Some of the most common bipolar views of 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., personalities, background, motivations and beliefs) can affect scientists in selecting, interpreting, recording, reporting evidence and generating conclusions or theories (Abd-El-Khalick et al., 1998; Murcia & Schibeci, 1999; Thye & Kwen, 2003). For example, 46% of pre-service teachers in Thye and Kwen's study believed that the same piece of evidence or the same set of data can be subject to multiple interpretations. However, many pre-service teachers strongly believed objectivity in science that is firmly based upon theory-free or value-free observation, because it leads to the validity of scientific knowledge (Murcia & Schibeci, 1999). They believed that 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 good scientists.

Creativity and imagination are closely related to subjectivity in science. Some pre-service teachers acknowledged the role of creativity and imagination in the process of scientific investigation such as setting hypotheses, designing experiments or generating conclusions (Abd-El-Khalick et al., 1998; Bell et al., 2000; Murcia & Schibeci, 1999). They subsequently dismissed the view of science as a completely objective and rational activity (Bell et al., 2000). However, some pre-service teachers denied the role of creativity and imagination in science. They believed that science is fact or truth that creativity does not have a place, because facts speak for themselves, there must not be any interpretation of them (Murcia & Schibeci, 1999; Thye & Kwen, 2003).

Scientific enterprise. Most student teachers recognized the social and cultural influences on the scientific enterprise (Haidar, 1999; Mellado, 1997; Murcia & Schibeci, 1999; Rubba & Harkness, 1993; Tairab, 2001). These influences may come from professional organizations, funding sources and peer review (Bell et al., 2000). Research funding or funding agencies are seen as important factors influencing the direction of science (Murcia & Schibeci, 1999). On the other hand, some student teachers overlooked the influences of social and cultural factors on scientific enterprise. Many of them sometimes neglected science as a social enterprise or a form of human cultural activity (Abd-El-Khalick et al., 1998; Tairab, 2001).

It is, maybe, an easy task for pre-service teachers to recognize the interaction between science and technology: Science is the knowledge base for technology, and technology influences scientific advancement. However, distinguishing between science and technology is probably a very difficult task (Rubba & Harkness, 1993). The common misunderstanding about science and technology is that technology is applied science (Tairab, 2001).

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

Most of 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 NOS, there were only three studies related to pre-service teachers' conceptions of 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 emphasized a quantitative approach. Surprisingly, all of them utilized the same questionnaire, consisting of 94 items corresponding to the four scales of NOS: Assumptions of 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 that in general, the pre-service teachers demonstrated a high level of understanding of NOS. The content background variable significantly yielded different levels of understanding of NOS, while the gender variable did not.

This study aims to contribute to the relatively limited literature on pre-service physics teachers' conceptions of NOS. The findings coming up from this study may inform involved stakeholders about the current state of pre-service physics teachers' understanding of NOS and subsequently guide them for planning programmes or curricula to promote understanding of NOS at the pre-service level. The research question guided the present study is: What are pre-service physics teachers' conceptions of NOS, particularly scientific knowledge, scientific method, scientists' work and scientific enterprise?

Methodology

The author utilized the MOSQ (myths of science questionnaire), as shown in Table 1, to explore pre-service physics teachers' conceptions of NOS. The MOSQ consists of 14 items concerning four main aspects of NOS: (1) scientific knowledge (Items 1-4; 8-9); (2) scientific method (Items 5-7); (3) scientists' work (Items 10-11); and (4) scientific enterprise (Items 12-14). 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*. The MOSQ requires respondents to select which of three responses: "Agree", "Uncertain" or "Disagree" that best fits their opinion of the item statement and provide their supporting reasons.

Table 1

The MOSQ

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

Statements	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

The author described the construction and utilizations of the MOSQ with pre-service and in-service science teachers in details in previous articles. In this study, the author tried out the MOSQ with 12 pre-service physics teachers at one university in the central region of Thailand and the reliability of the MOSQ was 0.76.

In the first semester of the 2008 academic year, the author administered the MOSQ to 17 pre-service physics teachers who have studied in a five-year science teacher preparation programme at one university in the central region of Thailand. The author also interviewed these teachers individually to clarify any ambiguities found in their completed MOSQ.

In data analysis, the author read each response carefully and interpreted it into three groups: (1) informed;

(2) uncertain; and (3) uninformed. After that, the author asked three science educators to independently validate the interpretations of the responses. The agreement rate of experts was 93%. The disagreement of interpretation was resolved through the meeting.

Results and Discussion

A majority of the respondents (15 of 17) were female. There were five, two, three, five and two participants in the first, second, third, fourth and fifth years of study respectively. More than one-third of the participants (7 of 17) were 19 years old. The participants' age range was 19 to 22 years old. Table 2 shows the pre-service physics teachers' conceptions of NOS revealed by the MOSQ.

Table 2

Pre-service Physics Teachers' Conceptions of NOS

Items	Number of respondents		
	Uninformed	Uncertain	Informed
Item 1	2	7	8
Item 2	6	5	6
Item 3	13	4	0
Item 4	0	1	16
Item 5	10	4	3
Item 6	3	7	7
Item 7	0	7	10
Item 8	12	4	1
Item 9	6	5	6
Item 10	1	1	15
Item 11	12	5	0
Item 12	7	1	9
Item 13	0	4	13
Item 14	1	4	12

Scientific Knowledge

Nearly a half of the participants (8 of 17) did not believe that hypotheses are developed to become theories only, but they can become laws or anything else. The participants, who were unsure, also argued in a similar way. However, one participant in the unsure group stated that since the secondary level he had remembered, hypotheses are developed to become theories only. Another participant also added that scientists test hypotheses with experiments and come up with theories.

Six participants believed that scientific theories are less secure than laws. Their main reasons were: Laws are real because they can explain everything in nature; Laws are accurate because they are proven again and again; Theories can be discarded; Theories explain laws, so laws are more secure. On the contrary, six participants who disagreed, mentioned that: Theories are widely accepted; Theories and laws are equally credible; Theories and laws can be changed; and theories explain laws. Noticeably, the reason of "theories explain laws" appeared in both agreed and disagreed groups. The participants with unsure responses still struggled in differentiating the meanings of theory and law.

A majority of the participants (13 of 17) held an uninformed conception that scientific theories can be developed to become laws. They argued that: When theories are proven to be real, accurate, explainable and credible enough, they become laws; Theories explain laws; Theories are the components of laws; and laws come from theories. Some participants were unsure whether or not scientific theories can be developed to become laws because their meanings might not differ. Noticeably, again, the reason of "theories explain laws" appeared in both agreed and unsure groups.

The pre-service physics teachers in this study, like other pre-service teachers around the world, commonly held uninformed conceptions about the roles of, and relationship between hypotheses, theories and laws. Frequently, they cannot differentiae the roles of theories and laws: Laws are statements or descriptions of discernible patterns developed to account for observable phenomena; Theories are inferred explanations for those phenomena. These two types of knowledge play different roles in science. Most pre-service physics teachers strongly believed in the laws-are-mature-theories-fables (Abd-El-Khalick et al., 1998; Rubba & Harkness, 1993; Thye & Kwen, 2003) that potentially lead them to perceive theories as less secure than laws (Ogunniyi, 1982). The regularity of the nature, which is described by scientific laws, is very hard to vary as time goes by. This is why people generally perceive scientific laws are more mature than scientific theories (Marshall, 2007).

Nearly all participants, except one, recognized the tentative nature of science. They believed that scientific knowledge can be changed and commonly raised the discovery of new evidence and the creation of new technology or instruments as the major factor for change. Some of them also mentioned that scientific knowledge change according to the discovery of more credible, clear and accurate reasons. This finding supports the literature that the tentativeness of science or dynamic of science is highly recognized by pre-service teachers (Abd-El-Khalick et al., 1998; Bell et al., 2000; Craven et al., 2002; Mellado, 1997; Murcia & Schibeci, 1999; Nott, 1994; Palmquist & Finley, 1997). However, the participants in this study did not explicitly raise subjectivity or creativity as key factors making science tentative, as Bell et al. (2000) noticed. 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).

About two-third of the participants (12 of 17) held an uninformed conception that accumulation of evidence makes scientific knowledge more stable, or what we called "Baconian induction" (McComas, 1998, p. 58). Eight of them stated that accumulation of evidence benefits more accurate, credible or durable scientific knowledge. However, one participant from the disagreed group and two participants from the unsure group mentioned that accumulation of evidence does not guarantee the stability of scientific knowledge, and only single evidence found being more credible or accurate can discard all accumulated evidences and make them useless. Similarly to other pre-service teachers, pre-service physics teachers struggle to perceive scientific progress as a revisionary process rather than a cumulative process (Brickhouse, 1990). They strongly believed in Baconian induction that leads them to view scientific knowledge as cumulative—Individual pieces of evidence are collected and examined until a law is discovered or a theory is invented (Haidar, 1999). Induction, as proposed by Francis Bacon (1561-1626), is still popular because they have always worked up to now. The success of inductive arguments relies heavily on the regularity of the natural phenomena that enables them to make reliable predictions (Marshall, 2007). Only few pre-service teachers are aware of the problem of induction, that is, even a preponderance of evidence does not guarantee the production of valid knowledge (McComas, 1998). As Karl Popper (1902-1994) argued, no amount of data can confirm a hypothesis, but one counter-instance can refute it (Marshall, 2007).

Six participants held an uninformed conception that a scientific model expresses a copy of reality, because such model is created from real investigation or made from things exist real in nature. On the contrary, six participants argued that a scientific model can not express a copy of reality, because they are created from scientists' imagination or guess. Similarly, the participants with unsure responses wondered that imagination may involve the invention of a scientific model. Whether or not a scientific model expresses a copy of reality is one major problem for pre-service physics teachers to understand NOS like other pre-service teachers found in Ogunniyi (1982) and Thye and Kwen (2003). In similar to Haidar (1999) and Bell et al. (2000), the pre-service teachers, who believe a scientific model is not a copy of reality, generally raise scientists' imaginations or educated guess as a major reason to support their beliefs.

Scientific Method

Nearly two-thirds of the participants (10 of 17) held an uninformed conception that the scientific method is a fixed step-by-step process. They stated that to do science is to exactly follow the scientific method. On the contrary, the main argument of the disagreed and unsure participants was that a process of the scientific method can be changed to suit a particular investigation. The wide propagation of the universal, step-wise scientific method in school science textbooks may be one of the major factors enhancing pre-service physics teachers' uninformed conception of NOS regarding the scientific method (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 pre-service teachers to portray science as a rigid procedural investigation leading to reliable, valid and dependable knowledge (Palmquist & Finley, 1997).

Similarly to Item 6 (see Tables 1 and 2), the uncertain responses were high (7 of 17) in the "Science and the scientific method can answer all questions" item. Black magic and spirits are frequently raised by the participants with unsure and disagreed responses as things science and the scientific method can not explain. However, two participants in the agreed group argued that science can explain everything including even ghosts or spirits.

Nearly two-thirds of the participants (10 of 17) disagreed that "Scientific knowledge comes from experiments only" by mentioning other methods to investigate in science, such as observation, survey, documentary review and imagination. The others, even were unsure, also raised observation and documentary review as other methods for scientific investigation. This study shows that observation is a popular method that many pre-service teachers raised as an alternative method of scientific investigation (Thye & Kwen, 2003).

Scientists' Work

Nearly all participants, except two, held an informed conception that "Scientists do use creativity and imagination in developing scientific knowledge". They mentioned that scientists' creativity and imagination are involved when they set hypotheses, design experiments or create theories and models. One participant was unsure whether or not creativity and imagination involve in developing scientific knowledge. Conversely, another participant insisted that science involves scientists' clear reasoning, and there is no place for creativity and imagination.

About two-third of the participants (12 of 17) perceived that "Scientists are open-minded without any biases". They mentioned about open-mindedness without any biases as a desirable characteristic of good scientists, nevertheless, the scientific knowledge scientists created may be flawed. However, the other participants were unsure by stating that open-mindedness without any biases depends on individual scientists. Some scientists may have biases, which are originated from their prior knowledge, experience and perspectives. It is hard for scientists to do science with no bias.

The pre-service physics teachers in this study highly regard creativity and imagination as important in developing scientific knowledge, especially creating scientific models and designing experiments (Abd-El-Khalick et al., 1998; Bell et al., 2000; Murcia & Schibeci, 1999). This implies that they recognize subjectivity in science. However, most of them still believe that "Scientists are open-minded without any biases" (Palmquist & Finley, 1997). They did not aware that scientists, as individuals, stick with their own accepted paradigms for most of time (Marshall, 2007). This implies that they also believe in objectivity in science. This study shows that some pre-service physics teachers can hold conflicting conceptions of NOS within their conceptual scheme.

Scientific Enterprise

More than a half of the participants (9 of 17) did not believe that "Science and technology are identical". Six of them stated that science is a body of knowledge, and technology is an application of scientific knowledge. One participant believed that science is a principle of reality, and technology is invented from creativity. One participant stated that science and technology are related to and support each other. However, seven participants believed that "Science and technology are identical". Their main reasons were: (1) Science accompanies technology; (2) Science and technology develop together and integrate to each other; (3) People use science and technology together; and (4) Technology is developed from science. One unsure participant mentioned that science closely links to technology, and it is hard to distinguish science from technology.

The differentiation between science and technology is a difficult task for pre-service teachers (Rubba & Harkness, 1993). This problem is culturally rooted, because people tend to point to artifacts and systems that followed scientific discoveries, such as atomic physics leading to nuclear power generation and electrical research leading to dynamos and transformers. Consequently, physics 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 (Tairab, 2001).

More than two-thirds of the participants (13 of 17) recognized scientific enterprise as social enterprise. They argued that science needs cooperation of people from different fields. Doing science cooperatively benefits from sharing diverse opinions and ideas that leads to less mistakes and better results. Two of them mentioned that science is social enterprise, because it impacts directly on society. Four participants, who were unsure, noticed that some scientific experiments accomplished by a team of scientists with different fields of expertise.

About two-thirds of the participants (12 of 17) recognized the societal, political and cultural influences on scientific knowledge. Some areas of science, such as cloning, are undeveloped because of societal ban. Current interests and needs of people in society also direct scientific investigation such as alternative energy. However, one participant denied the influences of society, politics and culture on scientific knowledge. Most pre-service physics teachers, like other pre-service teachers, perceive 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; Nott, 1994; Rubba & Harkness, 1993; Tairab, 2001). There are only a few teachers who did not perceive the influences of society, culture and politics on science advancement (Tairab, 2001).

Overall, the five most common uninformed conceptions of NOS held by the pre-service physics teachers in this study were: (1) Scientific theories can be developed to become laws; (2) Accumulation of evidence makes scientific knowledge more stable; (3) Scientists are open-minded without any biases; (4) The scientific method is a fixed step-by-step process; and (5) Science and technology are identical. On the contrary, the five most common informed conceptions of NOS were: (1) Scientific knowledge can be changed; (2) Scientists do use creativity and imagination in developing scientific knowledge; (3) Scientific enterprise is a social enterprise; (4) Society, politics and culture do affect the development of scientific knowledge; and (5) Scientific knowledge does not come from experiments only.

Conclusions and Implications

Pre-service physics teachers' thorough understanding of NOS appears as a prerequisite for effective classroom practice aiming to promote learners to become scientifically literate citizen. Preparing pre-service physics teachers to acquire an adequate understanding of NOS should be a basic requirement for teacher preparation programmes. However, in some programmes, pre-service physics teachers arrive with largely unexamined conceptions of NOS, and too often leave the programmes without these conceptions being challenged. The present study qualitatively revealed several uninformed conceptions of NOS held by the pre-service physics teachers, who have attended one teacher preparation programme in a Thai context, that is: (1) the relationship between theory and law; (2) science as cumulative; (3) subjectivity in science; (4) the scientific method; and (5) the relationship between science and technology. These uninformed conceptions urged the author, as a science educator, to plan for some interventions in the programme in order to help the author pre-service teachers attain informed conceptions of NOS. Several implications can be drawn from the present study.

The MOSQ employed as a research instrument in this study may be useful for other physics or science educators in exploring their pre-service physics or science teachers' conceptions of NOS and in tracking their pre-service teachers' conceptual development. It effectively yields both quantitative and qualitative data regarding respondents' understanding of NOS.

If one accepts the importance of understanding of NOS, then physics teacher education programs are obligated to develop new physics teachers who understand a contemporary view of NOS and its application to teaching. NOS should not be anticipated as a side effect or secondary product of hands-on inquiry. Rather, it should be explicitly mentioned and included in physics teacher education programmes. Based on empirical studies (Abd-El-Khalick, 2002; Akindehin, 1988; Billeh & Hassan, 1975; Carey & Strauss, 1968; King, 1991; Ogunniyi, 1982; Schwartz, Lederman, & Crawford, 2004), explicit-instruction on NOS in teacher education has more potential to improve pre-service teachers' understanding of NOS than implicit-instruction. However, explicitly teaching NOS outside a physics context may yield only a limited effect on changing and improving student teachers' understanding of NOS. Therefore, NOS-associated activities and discussions should not be an add-on, but should be tightly linked to physics content. Embedding content with NOS in various activities may help physics teacher educators overcome their time constraint (Nott, 1994; Abd-El-Khalick, 2002; Kapon, Ganiel, & Eylon, 2009).

Teachers' different views of the subjects they taught arise from their views about how children learn. Another aspect that should be included in physics teacher education programmes is constructivist epistemology. Growing awareness of and commitment to constructivism among prospective teachers have the potential to improve their conceptions of NOS, especially the tentativeness of science and theory-laden observation

(Pomeroy, 1993).

It is hoped that this study will assist physics or science educators globally to better understand pre-service physics teachers' misunderstandings of NOS, and will guide them to more effective pedagogical strategies or curricular framework to improve pre-service teachers' understanding of NOS. This study, however, has the limitation with respect to its generalization because of a small sample of participants.

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