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# A Study of New Models for Scientific Inquiry Activity through Understanding the Nature of Science (NOS): - A Proposal for a Synthetic View of the NOS -

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**Abstract:** In this study, it is assumed that understanding the nature of science (NOS) would enhance students' performance of scientific inquiry in more authentic ways. The ultimate goal of this study is to suggest new models for developing scientific inquiry activities through understanding the NOS by linking the NOS with scientific inquiry. First, the various definitions and statements of the NOS are summarized, then the features of the developmental nature of scientific knowledge and the nature of scientific thinking based on the philosophy of science are reviewed, and finally a synthetic list of the elements of the NOS is proposed, consisting of three categories: the nature of scientific knowledge, the nature of scientific inquiry, and the nature of scientific thinking. This suggested synthetic list of the NOS is used to suggest a model of scientific inquiry through the understanding of the NOS. This list was designed to provide basic standards regarding the NOS as well as practical guidance for designing activities to improve students' understanding of the NOS.

Key words: the nature of science, scientific inquiry, science education curriculum, scientific knowledge, scientific inquiry skills, scientific thinking.

## I. Introduction

Many researchers have emphasized that science curriculum needs to be philosophically valid (e.g., Hodson, 1988). Therefore, the importance of understanding the NOS has been stressed in science curriculum. For instance, the NRC (1996) has stated, "Students should develop an understanding of what science is, what science is not, what science can and cannot do, and how science contributes to culture." (NRC, 1996, p.21), the NRC (2000) emphasized again the importance of understanding the NOS as follows: "Understandings of scientific inquiry represent how and why scientific knowledge changes in response to new evidence, logical analysis, and modified explanations debated within a community of scientists." Moreover, the NSTA (2000) said, "All those involved with science teaching and learning should have a common, accurate view of the nature of science."

In 'Science for All Americans', the AAAS (1994) described the features of the NOS in connection with the scientific worldview, scientific inquiry, and the scientific enterprise (details in Table 1). The physics 11 and 12 curriculum of the Province of British Columbia in Canada (PBC, 1996) described, "the revised physics courses seek to introduce to students the nature, scope, skills, methods, and relevance of physics ... An understanding of the content therefore involves an understanding of the nature of the methods of inquiry that characterize physics as a discipline. (p. 2)"

Donnelly (2001) reviewed how the NOS had been introduced in the National Curriculum for England and Wales, and showed some instances of the NOS in the curriculum's 1999 revision as follows: "Scientific controversies can arise from different ways of interpreting empirical evidences, and (social, historical, moral and spiritual) contexts may affect whether or not (scientific) ideas are accepted."

***Why the NOS in science education?:*** Then, why is the understanding the NOS so important in science education? The first reason is that understanding the

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NOS is expected to lead students in a direction that will facilitate their achieving scientific literacy (Matthews, 1994; Lederman, 1999; Hand *et al.,* 1999; AAAS, 1994; NRC, 1996; NSTA, 2000; Bell and Lederman, 2003).

NRC (1996, p.21) noted that, "An explicit goal of the National Science Education Standards is to establish high levels of scientific literacy ... Scientific literacy also includes understanding the NOS," Hand *et al.* (1999) suggest a broader view of scientific literacy as involving understanding of scientific inquiry, reasoning and epistemological beliefs in the construction, dissemination, and application of science knowledge. Abd-El-Khalick and Lederman (2000) and Osborne *et al.* (2003) suggest that an adequate understanding of the NOS is an essential component of scientific literacy. More concretely, Bell and Lederman (2003) assert that citizens who comprehend the NOS well would better be able to distinguish scientific claims from pseudoscientific claims and also better be able to apply scientific knowledge to their everyday lives. Kolsto (2001) argues that understanding the NOS was necessary for students to be able to debate controversial socio -scientific issues as future citizen.

Even though the relationship between understanding the NOS and the conceptual understanding of science is not straightforward (Bell and Linn, 2002), there are also reports that understanding the NOS can help a student's conceptual understanding. Windschitl and Andre (1998) found that college students with a more advanced epistemological belief (e.g., they denied that 'knowledge is certain' and 'most words have a clear single meaning') showed greater possibility of making conceptual changes in a constructivist learning environment using computer simulation. Tsai (2001) stresses that a sound understanding of the NOS could help students' making conceptual changes by facilitating accommodation of new materials, incorporation of new evidence, and new conceptualization based on defensible evidence.

Another important reason for emphasizing the NOS in science education is that it is closely related to scientific inquiry. Vhurumuku *et al.* (2006) said, "...students' decisions on how to carry out investigations, what observations to make and record, which experiments to repeat, and what counts as a valid conclusion might be influenced by ... their images of the NOS." Likewise, many educators believe that the understanding of the NOS can give students a basis for conducting scientific inquiry better (Schauble *et al.,* 1995; Sandoval and Reiser, 2004; Toth *et al.,* 2002). For instance, Cleminson (1990) assumes that science courses would be better if the courses reflected the NOS in a quality way. Sandoval and Reiser (2004) argue that understanding epistemic aspects of performing science is necessary for deep understanding of science and an ability to really conduct scientific inquiry. In addition, Schauble *et al.* (1995), Bell and Linn (2000), and Toth *et al.* (2002) also observed that understanding the NOS could enhance students' performance of scientific inquiry.

This study is particularly concerned with the close relationship between the NOS and scientific inquiry. However, even though the NOS is closely related to conducting scientific inquiry, many science educators have pointed out that students' scientific inquiry activities in school do not reflect the NOS (Driver *et al.* 1996). Hodson (1998) also emphasizes that practical activities should be grounded on a view of science that was philosophically sound. He further criticizes that most schools and science textbooks did not meet this requirement. Recently, Chinn and Malhotra (2002) also found that almost all science textbooks did not take an epistemologically sound standpoint.

Therefore, it has been pointed out that the failure of scientific inquiry was attributed to the lack of appropriate NOS instruction in the science curriculum and that lack of understanding the NOS was one of the constraints impacting teachers' enactment of inquiry-based instruction (Hodson, 1998). In fact, Brickhouse (1990) observed that teachers who did not consider that scientists make observations based on a theory and taught products and process of inquiry separately, had students focused only on the procedure itself without considering the link the procedure might have with theories. Roehig and Luft (2005) observed that teachers who viewed scientific knowledge as being verified through rigorous experimentation usually did not allow students to investigate their own questions, to devise their own procedures, or to draw their own conclusions. These teachers usually wanted students to find out 'right answers' straightforwardly.

Students' lack of understanding the NOS may also be a prohibiting factor when conducting scientific inquiry in a more authentic way. For instance, students who think scientific knowledge can be obtained directly from data analysis and who are not aware of the role of scientific knowledge for interpreting and evaluating data may collect more data only for improving accuracy of results (Vhurumrku *et al.,* 2006).

Therefore, effort for linking scientific inquiry with the NOS is necessary. However, even though there are many studies regarding the NOS and scientific inquiry, many of these studies have been conducted separately. As a result, research into linking the NOS and scientific inquiry is currently insufficient (Sandoval, 2005; Lederman, 1998; Matthews, 1998). For instance, Sandoval (2005) noted, "Curiously, until very recently research on students' belief about the NOS, has occurred largely independently of research on inquiry."

Making the link between the NOS and scientific inquiry is not easy task. Simply introducing or instructing the NOS without any concrete connection with scientific inquiry does not guarantee good performance of scientific inquiry automatically. For instance, Jin (2005) reported that only 36% of science teachers responded that teaching the NOS in the first chapter of the 10$^{th}$ grade science textbook should improve students' scientific inquiry ability. Schauble *et al.* (1995) and Rudolph (2005) also pointed out that studying the first chapter for the scientific methods in a typical textbook did not guarantee students' understanding the nature of experimentation.

***Synthetic view about the NOS:*** The ultimate goal of this study is to discuss how we can help students' scientific inquiry through understanding the NOS. To accomplish this aim, a prerequisite requirement is that we need to determine which aspects of the NOS should be considered and reflected when performing scientific inquiry. This determination is the main theme of this article.

Regarding the NOS, many researchers have defined the NOS and described the components of the NOS. For instance, Lederman *et al.* (2002) viewed the nature of science (NOS) as the epistemology and sociology of science, science as a way of knowing, or the values and assumptions inherent to scientific knowledge. Regarding the epistemology of science, Sandoval (2005) noted, "... scientific epistemology is a description of the nature of scientific knowledge, including the sources of such knowledge, its value, scientifically appropriate warrants, and so on."

However, researchers have pointed out that there is no complete consensus or general agreement concerning the contents, level, and scope of the NOS for secondary school students. For instance, Alters (1997) summarized 39 tenets of the NOS stated in science education literature and examined whether these tenets were in agreement with philosophers of science. As a result, he found that the philosophers of science expressed significant disagreement with the tenets. He, therefore, insisted that the tenets of the NOS must be reconsidered. Rudolph (2000) argued that one of the reasons that any emphasis of the NOS in science curriculum had met with little success was because there had been various competing, often conflicting, views of the nature of scientific inquiry.

Recently, some efforts have been made to provide a view of consensus on the NOS. For instance, Lederman *et al.* (2002) suggested seven broadly accepted aspects regarding the epistemology of science as follows. Scientific knowledge (1) is tentative, (2) is theory laden, (3) depends on an empirical basis, (4) is creative, (5) is socially embedded, (6) is based on observation and inference, and (7) theories and laws have different function. Sandoval (2005), focusing only on epistemological ideas which can be expected to influence students' scientific inquiry, described the NOS with four features: (1) scientific knowledge is constructed; (2) scientific methods are diverse; (3) theories and laws are different forms of scientific knowledge; and (4) scientific knowledge varies in certainty. Recently, Osborne *et al.* (2003) summarized 30 themes of the NOS that should be taught to students in three categories: nature of scientific knowledge, methods of science, and institutions and social practices in science.

Although even with these efforts for establishing agreement about the NOS, it is found that the NOS can be described differently according to researchers' concerns or intentions. That is, Lederman *et al.* (2002) focused mainly on the nature of scientific knowledge. Sandoval (2005) included the nature of scientific inquiry in the NOS. Even though Osborne *et al.* (2003) obtained comprehensive views concerning the NOS from science educators, scientists, philosophers, and sociologists of science using the Delphi method, they included the teaching of scientific inquiry skills itself, rather than the nature of scientific inquiry. For instance, they noted, "Students should be taught that science uses the experimental method" but they did not note concrete instances of the 'nature' of experimental method, such as the theory of ladenness of scientific observation, logical structure of scientific explanation, or the limit of the inductive method. In particular, they stressed the role of scientific institutes and the nature of scientists, but these aspects are not usually considered as essential components of the NOS.

Therefore, we need to suggest a more synthetic view about the NOS as a starting point for establishing a consensus on the NOS for secondary school students. Of course, it may be impossible to encompass all literature relating to the NOS and to establish a unified standard reflecting all opinions about the NOS. Moreover, this unity may be impossible because scientific inquiry, intrinsically, has a multifaceted, complex, and dynamic nature (Abd-El-Khalick and Lederman, 2000). Moreover, the meaning of the NOS is subject to be different from the different background of philosophy of science or different purpose for treating the NOS in secondary science schools.

The purpose of this article is not to develop an absolute and unified list of what constitutes the NOS, but to suggest a more comprehensive view regarding the NOS by listing the statements describing the major features of the NOS in more concrete forms through a wider review about the NOS. Then, it is hoped that this synthetic view could be widely used in various contexts of teaching the NOS and modified in the future through wider considerations and additional research related to the NOS.

## Ⅱ. Purpose and the Structure of This Study

The final purpose of this study is to suggest new models for teaching scientific inquiry through understanding the NOS. Before, suggesting these models, in this article, a synthetic view of the NOS for secondary school students is proposed.

For a synthetic list of the NOS, definitions and statements describing features of the NOS in the science curriculum and teaching efforts to improve understanding of the NOS are listed (see Fig. 1). This review provides information concerning concrete elements of the NOS for the purposes or goals of teaching science. In addition to this review, the philosophy of science is reviewed to obtain ideas involving how scientific thinking takes a role in scientific inquiry and how scientific knowledge has developed (Fig. 1). Of course, a study on philosophy of science is very extensive work and it is really difficult to review all of the literature in these areas. Moreover, we agree with Matthew's opinion that it is unrealistic to expect students or teachers to develop understandings of experts in the philosophy of science (Matthews, 1994, 1998). Therefore, the primary purpose of this review was not to teach philosophy of science, itself, to students directly, but to obtain the basic information and implications regarding the nature of scientific thinking and developmental nature of scientific knowledge for secondary school students. Because it has been found that these aspects of the NOS have to date not been discussed sufficiently discussed, it is hoped that this work will supplement the review of the NOS in the science curriculum and teaching efforts. In the final part of this article, a

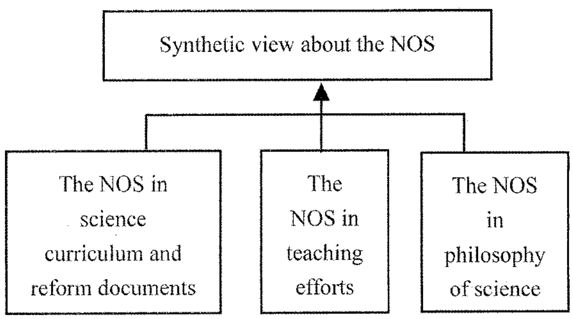


**Fig. 1** *The structure of this study*

synthetic list of the NOS for secondary school students is proposed, consisting of three categories: the nature of (1) scientific knowledge, (2) scientific inquiry process skills, and (3) scientific thinking.

## III. Statements Describing Features of the NOS

This article started from the review of the statements regarding the NOS in science curriculum and reform documents, from the review of contents and goals of teaching efforts for improving understanding of the NOS, and from the review of the philosophy of science.

### 1. NOS in curriculum and reform documents

Three aspects of the NOS from the AAAS reform document (AAAS, 1994) and nine elements of the NOS in NSTA (2000) are summarized in Table 1. From a study by Abd-El-Khalick and Lederman (2000), two elements from the California Department of Education and eight elements from the NRC were summarized. More comprehensively, McComas and Olson (1998) examined international science education standards documents in the USA, Australia, New Zealand, and Canada. They classified insights, statements, and assumptions about the NOS into four categories: 18 elements for philosophical, 6 for sociological, 4 for psychological and 10 for the historical category. In Table 1, common elements of the NOS, appearing in at least 5 documents, are listed.

McComas and Olson's study provides comprehensive information regarding the NOS in the science curriculum and reform documents, but their categorization needs to be discussed. According to McComas

**Table 1**

*NOS in science curriculums and reform documents*

| Source | The NOS |
|---|---|
| AAAS (1994) | The Scientific Worldview: (1) Science is understandable; (2) Scientific ideas are subject to change; (3) Scientific knowledge is durable; and (4) Science cannot provide complete answers to all questions.<br>Scientific Inquiry: (5) Science demands evidence; (6) Science is a blend of logic and imagination; (7) Science explains and predicts; (8) Scientists try to identify and avoid bias; and (9) Science is not authoritarian.<br>Scientific Enterprise: (10) Science is a complex social activity; (11) Science is organized into content disciplines and is conducted in various institutions; (12) There are generally accepted ethical principles in the conduct of science; and (13) Scientists participate in public affairs both as specialists and as citizens. |
| NSTA (2000) | (1) Scientific knowledge is tentative; (2) There is no single step-by-step scientific method; (3) Creativity is a vital component for producing scientific knowledge; (4) Science precludes supernatural elements for producing scientific knowledge; (5) Laws are generalizations describing phenomena while theories are explanations of it; (6) Science is conducted corporately; (7) Science is affected by existing scientific knowledge and social/cultural context; (8) Science has changed both evolutionally and revolutionary; and (9) Basic scientific research is not directly concerned with practical outcomes. |
| Adb-El-Khalick & Lederman (2000) | The California Department of Education (1990): (1) Scientific activities are theory-driven; and (2) Scientists conduct their investigations from within certain frameworks of reference.<br>NRC (1996): The NRC emphasized the (3) Historical, (4) Tentative, (5) Empirical, (6) Logical, and (7) Well-substantiated nature of scientific claims; and also (8) Values of skepticism, and (9) Open communication, as well as (10) The interaction between personal, societal, and cultural beliefs in the generation of scientific knowledge. |
| McComas & Olson (1998) | Philosophical Aspect: (1) Scientific knowledge is tentative; (2) Science or scientific knowledge depends on observation, empirical evidence, and skepticism; and (3) Science is an attempt to explain phenomena.<br>Sociological Aspect: (4) All cultures can contribute to science; (5) Science is a human endeavor; (6) New knowledge must be reported clearly and openly; (7) Scientists require accurate record keeping and (8) Repeatability and trustful reporting; (9) Scientists make ethical decisions and work collaborate.<br>Psychological Aspect: (10) Scientists are creative and must be open to new ideas.<br>Historical Aspect: (11) Change in science occurs gradually and/or through revolution, (12) Science has global implications; (13) Science is part of cultural tradition; (14) Science has played an important role in technology; and (15) Science builds on what has gone before. |

and Olson, the NOS may be classified into four categories: philosophical, sociological, psychological, and historical aspects. However, this study did not have any direct intention that students must know the content of philosophy of science or history of science, itself. Rather, concern has been focused on what students actually do, think, and know when doing science. Students 'do' scientific inquiry, 'think' when sciencing and 'know' scientific knowledge. Therefore, students are required to recognize the nature of what they are doing, thinking, and knowing. Then, the statement that 'scientific knowledge relies on empirical evidence' would be better involved in the category of 'the nature of scientific knowledge' rather than involved in the 'philosophy' category by McComas and Olson (1998). Also, 'observation is theory-laden' would be a better fit in the category of 'the nature of scientific inquiry' than in 'psychology'. Therefore, instead of adopting McComas and Olson's category, a new categorization of the NOS was used in this study: scientific knowledge, scientific inquiry, and scientific thinking.

## 2. The NOS in teaching efforts to improve understanding of the NOS

When aiming at conceptual change of students, identification of their misconceptions before instructing correct scientific concepts is required. Likewise, identification of teachers' and students' misunderstanding regarding the NOS can give us basic directions for teaching correct views about the NOS in schools. With regard to this need for identification, McComas (1998) and Hodson (1998) identified 15 and 9 myths concerning the NOS, respectively. Bell and Linn (2000) compared wrong views with sound views regarding the NOS (Table 2).

Which aspects of the NOS should be taught can be found in teaching efforts to enhance understanding of the NOS. Lederman and Abd-El-Khalick (1998), rejecting the assumption that simply conducting scientific inquiry will lead students to proper understanding of the NOS, developed activities consisting of three sections to instruct students in the contents of the NOS, explicitly. From the goals of each section, we can see what aspects of the NOS have been chosen as being worth teaching (Table 3). Applying a historical approach to teaching the NOS in secondary school, Ping-Kee Tao (2003) emphasized six aspects of the NOS in his science stories instruction. As shown in Table 3, Bianchini and Colburn (2000) selected six aspects of the NOS that could be instructed through a scientific inquiry activity. This study is of specific interest because implications for the link between the NOS and scientific inquiry can be drawn. With regard to learning goals related to the NOS, Bartholomew *et al.*, (2004) proposed nine NOS

**Table 2**
*Some myths regarding the NOS*

| Author | Myths regarding the NOS |
|---|---|
| McComas (1998) | (1) Hypotheses become theories that in turn become laws. (2) Scientific laws and other such ideas are absolute. (3) A hypothesis is an educated guess. (4) General and universal scientific method exists. (5) Evidence accumulated carefully will result in sure knowledge. (6) Science and its methods provide absolute proof. (7) Science is procedural more than creative. (8) Science and its methods can answer all questions. (9) Scientists are particularly objective. (10) Experiments are the principal route to scientific knowledge. (11) Scientific conclusions are reviewed for accuracy. (12) Acceptance of new scientific knowledge is straightforward. (13) Science models represent reality. (14) Science and technology are identical. (15) Science is a solitary pursuit. |
| Hodson (1998) | Nine Myths about Science: (1) Observation provides direct and reliable access to secure knowledge. (2) Science starts with observation. (3) Science proceeds via induction. (4) Experiments are decisive. (5) Science compromises discrete, generic processes. (6) Scientific inquiry is a simple, algorithmic procedure. (7) Science is a value-free activity. (8) The so-called 'scientific attitudes' are essential to the effective practice of science. (9) All scientists possess these attitudes. |
| Bell and Linn (2000) | Wrong Views: (1) Scientific knowledge is static. (2) Controversy results from scientists not considering each other's ideas.<br>Sound Views: (3) Scientific knowledge is dynamic. (4) Science involves discovery. (5) Scientists try to understand evidence and relate it to other things they know. |

**Table 3**
*NOS in teaching efforts*

| Author | NOS in instruction |
|---|---|
| Lederman and Abd-El-Khalick (1998) | Section 1 of the Activity: (1) Observation differs from inference. (2) Scientific knowledge is tentative. (3) Science is partly a product of human inference, imagination, and creativity.<br>Section 2 of the Activity: (4) Observation is theory laden. (5) A scientist can interpret the same evidence differently and formulate different hypotheses. (6) Testing hypotheses is in some respect subjective.<br>Section 3 of the Activity: (7) Scientific knowledge is empirically based. (8) Scientific models are not a copy of reality. (9) Scientific theories explain the phenomena but scientific laws describe the regularities of it. This last section emphasized the way of practicing inquiry skills such as observing, collecting data, inferring, hypothesizing, and testing hypotheses. |
| Ping-Kee Tao (2003) | (1) Scientific discoveries are for understanding nature, (2) Science and its methods cannot give answers to all questions. (3) Scientists usually work in collaboration. (4) Scientists carry out experiments to test their ideas, hypotheses, and theories. (5) Scientists need to be creative and imaginative, (6) Scientific theories are created by scientists to explain and predict phenomena. (7) Scientific knowledge has a tentative character. |
| Bianchini and Colburn (2000) | (1) No one right way necessarily exists to solve a problem in science. (2) Scientists can seemingly be doing the same thing, yet get different results. The differences are not necessarily because someone did something wrong. Examinations of carefully recorded procedures often provide explanations for disparate results. Thus, careful record keeping is important when doing science. (3) Scientific knowledge is created and verified on the basis of evidence, rather than authority. (4) Other than the need for evidence, no single way exists to know definitively whether a conclusion is true. (5) The establishment of scientific truth ultimately includes a social component. Thus, part of science involves scientists persuading each other of the validity of their conclusions. (6) Knowledge is not created simply by collecting data. Knowledge also ultimately depends on how scientists interpret their result. This, in turn, depends on their already existing knowledge and belief. |
| Bartholomew, Osborne, and Ratcliffe (2004) | (1) Experiments are used to test ideas. (2) Scientific knowledge is subject to change. (3) Science uses a range of methods, and there is no one scientific method. (4) Developing hypotheses and predictions is essential to the development of new knowledge. (5) Scientific knowledge is developed with its history. (6) Science involves creativity and imagination. (7) New scientific knowledge emerges from a continual and cyclic process of asking questions and seeking answers. (8) Scientific knowledge emerges from simply from the data but through a process of interpretation and theory building, and often scientists come to different interpretations. (9) Scientific work is a communal and competitive activity. |
| Lederman et al. (2002) | Scientific knowledge is (1) tentative, (2) empirically derived, (3) subjective or theory laden to a degree, (4) partially based on human inference, imagination, and creativity, (5) and socially and culturally embedded. (6) It is based on observation and inference, and finally (7) scientific theories explain phenomena, but laws describe them. |
| Sandoval (2005) | (1) Scientific knowledge is constructed. (2) Scientific methods are diverse. (3) There are various forms of scientific knowledge. (4) Scientific knowledge varies in certainty. |
| Akerson, et al. (2006) | (1) Scientific knowledge is tentative, that is, is subject to change. (2) There are multiple methods of inquiry, and those methods require empirical evidence. (3) Creativity is important in developing knowledge. (4) Scientific knowledge is subjective. (5) Scientific knowledge is developed within a social and cultural context. (6) Theory is evidence-based explanation of phenomena while law is an evidence-based description of it. (7) Inferences are explanations for observation. |

themes to be taught to students in school (Table 3). Lederman *et al.*, (2002), asserted that a common perception exists regarding the nature of scientific knowledge and described seven elements of the nature of scientific knowledge. Recently, Sandoval (2005) described four aspects of epistemology which students should know in order to understand and practice their inquiries effectively and in order to evaluate scientific claims in everyday socio-scientific contexts. In an attempt to teach elementary teachers the NOS and to examine the retention of teachers' improved views of the NOS, Akerson *et al.* (2006)

included seven elements as teaching ingredients of the NOS (Table 3).

### 3. Nature of scientific thinking and the developmental nature of scientific knowledge in the philosophy of science

Many discussions regarding the NOS in science education are already based on a philosophy of science. Therefore, a comprehensive and detailed review related to the philosophy of science may not be necessary. However, even though how scientific thinking, including induction, abduction, and deduction, takes a role in scientific inquiry and how scientific knowledge has developed are the main themes of the NOS, it is found that these aspects of the NOS have not been discussed in detail in the previous literature regarding the NOS. Therefore, here, the nature of scientific thinking and the developmental nature of scientific knowledge are reviewed in the area of philosophy of science and then summarized.

***Nature of scientific thinking:*** Even though inductive reasoning is a very useful thinking tool for drawing scientific knowledge describing general and universal features from a limited amount of data, scientific knowledge derived by induction cannot be justified as truth both logically and empirically (Chalmers, 1986). Understanding this aspect of inductive thinking can help a student to realize that scientific knowledge contains a basic limit concerning the truth of it and that scientific knowledge obtained by induction is a scientist's mental construct.

As many researchers have emphasized, the generation of a new hypothesis explaining the observed phenomena is one of the main themes of scientific inquiry (Klahr and Dunbar, 1988). Regarding this theme, Peirce (1955) suggests that scientific hypothesis may be generated through abductive reasoning, and Hanson (1961), based on the analysis of the process of the invention of Kepler's Law, also argued that formulating new ideas were not sourced from induction or deduction, but from abduction.

To help teachers teach students to generate scientific hypothesis, they need to understand the nature and the process of generating a hypothesis. For instance, based on the analysis of how college students generated explanatory hypotheses to explain a conflicting observation, Park (2006) found that background knowledge was important for generating a hypotheses and similarity-based reasoning such as analogical and abductive thinking was important for activating background knowledge. Furthermore, he proposed the model of similarity-based thinking (Fig. 2) and the model of generating explanatory (theoretical) hypotheses (Fig. 3).

Deduction takes basic roles in scientific explanation, prediction, and in testing scientific hypothesis. Hempel (1965) proposed the deductive-normative

| |
|---|
| New phenomena (P) to be explained has properties α, β, and γ. |
| Background Knowledge (BK) also has similarly properties, α', β', and γ'. |
| Then, the P and BK share similar properties with each other. |
| And the BK has another property δ'. |
| Therefore, it is worth inferring that P will also have property δ, even though δ has not yet been confirmed. |

**Fig. 2** *Model of similarity-based reasoning*

| |
|---|
| Observe new phenomena (P) to be explained. |
| Ask causal question why P happens. |
| Search for a hypothesis that may explain the P in the observers' Background Knowledge (BK). |
| Use similarity-based reasoning between P and BK. |
| Suggest a new theoretical hypothesis that may explain P. |

**Fig. 3** *Model of generating an explanatory theoretical hypothesis*

model of scientific explanation. According to Hempel, for the question 'Why did event E occur?', event E can be explained deductively from general laws and initial conditions (Fig. 4). Using this deductive model of scientific explanation, Park and Han (2002) observed that, using these logical conclusions, almost all students could draw a deductive logical conclusion correctly and they changed their prior misconception about force and motion. Therefore, understanding the nature and structure of scientific explanation can help students to make an explanation more logically based on a theoretical rationale.

According to Popper (1959), scientific knowledge cannot be confirmed but can only be falsified (Popper 1959, p.41). That is, the confirmation of a hypothesis cannot be logically warranted because the structure of the confirmation process is fundamentally equivalent to the 'affirmation of the consequent' among the syllogisms, in which a logically valid conclusion cannot be obtained (Fig. 5). However, in the case of the falsification process, in which the structure is the same as the 'modus tollens' of the syllogism, when the experimental evidence contradicts the prediction being derived from a hypothesis, the conclusion that the 'hypothesis is wrong' can be logically drawn (Fig. 6) (Park, *et al.,* 2001). Understanding the fact that the confirmation of a hypothesis cannot be certain, but only falsification of the hypothesis can be possible logically can enhance students

Deduction
- L1 and L2, Ln Causal Laws
- C1 and C2, Cn Statements of Initial Conditions
------------------------
→ E

**Fig. 4** *Structure of scientific explanation (Martin, 1972, p. 51)*

realize that scientific knowledge is tentative, subject to change, and cannot be the absolute truth. Moreover, it can help teachers be aware that school experiments that result in falsifying given theories rather than in proving them are of its value and that these kinds of experiments should be further developed for use in schools.

***Developmental nature of scientific knowledge:*** In Kuhn's (1970) paradigm shift describing the revolutionary feature of scientific knowledge development, the following interesting aspects of the NOS can be found. (1) Evidence conflicting with an existing paradigm can be neglected or refused by scientists and scientific communities because the existing paradigm has no appropriate languages or eyeglasses to evaluate it. (2) In order to discard the existing paradigm in front of anomaly, the suggestion of a new alternative paradigm explaining the anomaly is necessary. (3) Social and psychological aspects, rather than logic or reason, may take a decisive role in the paradigm shift. The first point is closely related to theory-laden observation and the psychological effect on conducting science as noted in various literature. The second point means that a new paradigm does not come from anomalous observation alone; that is, new scientific knowledge should be invented rather than discovered. This process of inventing a new paradigm is closely related to the generation of a new hypothesis. Third, factors including the effect of social and psychological factors on interpretation of anomalous experimental data, evaluation of new findings or theories, the decision to choose a new paradigm, have also been mentioned in several publications.

Premise 1: If hypothesis H is correct, then experimental result R is predicted.
Premise 2: Experimental result R is observed.
Conclusion: ?

**Fig. 5** *Process of hypothesis confirmation (affirmation of the consequent)*

Premise 1 : If hypothesis H is correct, then experimental result R is predicted.
Premise 2 : Experimental result R is not observed.
Conclusion: Hypothesis H is wrong.

**Fig. 6** *Process of hypothesis falsification (modus tollens)*

Kuhn's first and second points are similar to Lakatos's (1994) view concerning the development of scientific knowledge. However, Lakatos used the concept of 'protective belt' to explain the first point. That is, Lakatos described scientific theory as consisting of a core of basic principles and a protective belt of auxiliary assumptions and initial conditions around this core. Thus, when experimental evidence may contradict a theory, instead of rejecting the core of the theory, the theory can survive by modifying or adjusting the protective belt around the core in the face of anomalous experimental results.

Regarding the developmental nature of scientific knowledge, viewed differently from Kuhn's revolutionary view, Lakatos explained that scientific theory has evolved though successive articulation and refinement. As evidence for his view, he exemplified how Bohr's theory of the atom has evolved. In his analysis, it can be found that scientific knowledge can often be suggested with incomplete form, sometimes, even containing internal inconsistency. Conflicting data or rival theories may act as refining the initial incomplete knowledge rather than as falsifying it. Park (2003a, 2003b) also observed that students' ideas also develop evolutionally. That is, Park observed that, through the interview, students preceded diverse paths and multiple layers of conceptual change in the context of a simple electric circuit.

## 4. The synthetic list of the NOS for secondary school students

Based on the previous reviews, I proposed a list of statements describing the features of the NOS consisted of three categories: the nature of scientific knowledge, the nature of scientific inquiry, and the nature of scientific thinking (Table 5).

The nature of scientific knowledge is the most frequently mentioned aspect when describing the NOS (e.g., Lederman *et al.,* 2002). The developmental nature of scientific knowledge is involved in this category.

Scientific inquiry is conducted through active interaction between knowledge and inquiry skills like theory-laden observation. Therefore, the nature of scientific inquiry is closely related to the nature of scientific knowledge. However, because the basic goal of this study is to link the NOS to scientific inquiry, this study divides the nature of scientific inquiry from the nature of scientific knowledge.

In the third category, the nature and role of

**Table 4.** *The nature of scientific thinking and the developmental nature of scientific knowledge in the philosophy of science*

| Author(s) | Some important issues regarding the NOS |
|---|---|
| Charlemrs (1986) | (1) Generalized law through induction cannot guarantee the truth of law both logically and empirically. |
| Peirce (1955)<br>Hanson (1961) | (1) Scientific hypothesis is invented through abductive reasoning. |
| Hempel (1965) | (1) Scientific explanation is a deductive logical conclusion drawn by two premises including general laws and initial conditions. |
| Popper (1959) | (1) Scientific hypotheses cannot be confirmed logically.<br>(2) Scientific hypotheses can be falsified by deductive reasoning (modus tollens).<br>(3) Good scientific hypotheses are highly falsifiable. |
| Lakatos (1994) | (1) Scientific theories can survive frequently in front of conflicting evidence by modifying initial conditions, auxiliary hypotheses, and so on.<br>(2) To discard existing theory, anomaly, and a new theory explaining the anomaly are necessary.<br>(3) Scientific knowledge develops evolutionally through successive articulation and refinement of the knowledge.<br>(4) Scientific knowledge is often suggested in incomplete form. |
| Kuhn (1970) | (1) New theory can be refused by the existing paradigm.<br>(2) Conflicting evidence and new paradigms explaining the conflict are two necessary conditions for paradigm shift.<br>(3) Social aspects take an important role in the development of scientific knowledge.<br>(4) Scientific knowledge develops revolutionary. |

scientific thinking including induction, abduction, and deduction is summarized. As discussed earlier, even though these kinds of scientific thinking take a direct role in scientific inquiry, many science educators have not mentioned or discussed them in detail. Therefore, in this study, the nature of scientific thinking is described as an independent category.

The concrete statements regarding the NOS are based on the reviews in the earlier section; therefore, almost all elements of the NOS in Table 1, 2, 3 and 4 can be found in Table 5 except several elements describing general aspects of scientific work (e.g, scientists participate in public affairs both as specialists and citizens).

**Table 5**
*Synthetic list of the NOS*

| List of elements of the NOS |
|---|
| **1. The nature of scientific knowledge(SK)** |
| **11. Generation of SK** |
| 111. SK is constructed through scientific inquiry using various scientific inquiry skills. |
| 112. SK is not found from the nature but invented to understand the nature by scientists' imagination and creativity. |
| 113. SK is often suggested with an incomplete form. |
| 114. SK usually involves idea conditions and various assumptions. |
| 115. SK needs exact definitions and pursues simplicity. |
| **12. Acceptance and evaluation of SK** |
| 121. SK should be understandable to and accepted by the scientific community. |
| 122. SK should have supporting evidence, but conflicting evidence can exist. |
| 123. SK can be interpreted differently by scientists, therefore controversy is natural. |
| 124. SK often is accepted via authority, therefore, we need to have a doubt about SK. |
| 125. SK can be evaluated by ethical standards. |
| 126. SK generally pursues objectivity, but often has subjective aspect. |
| **13. Development of SK** |
| 131. SK has a history through which SK has developed. |
| 132. SK is durable, but tentative, therefore subject to change. |
| 133. SK has developed both evolutionary and revolutionary. |
| 134. To abandon existing SK, anomalous data and new SK explaining anomaly are required. |
| **14. Type and function of SK** |
| 141. Scientific theory is to explain and predict nature; while scientific law is to describe the regularities of nature. |
| 142. A scientific model is not a copy of reality but what a human constructs or has invented to explain nature. |
| 143. SK cannot answer all questions. |
| 144. SK is not necessarily practical to everyday life. |
| **2. The nature of scientific inquiry** |
| **21. Scientific inquiry skill** |
| 211. Observation depends on theory, therefore, often is not objective. |
| 212. Inference and observation can be discriminated but often act together. |
| 213. Measurement does not tell the true value but often includes errors and conflicting data. |
| 214. Same experimental data can be interpreted differently. |
| 215. Scientific hypothesis should be falsifiable, have a reasonable basis, and be a tentative explanation of nature. |
| 216. Same hypothesis can predict different results. |
| **22. Scientific inquiry process** |
| 221. Scientific inquiry can proceed experimentally or theoretically. |

222. Scientific inquiry process should be replicable and same results should be obtained by others.
223. Subjective aspects can be involved in the process of scientific inquiry.
224. Scientific inquiry can proceed through different procedures and methods rather than single step-by-step process.
225. Scientific inquiry can proceed cyclically and non-linearly.

**23. Social nature of scientific inquiry**

231. Scientific inquiry is often conducted corporately.
232. Scientific inquiry is affected by social, cultural, and political contexts.
233. Scientific inquiry can be prohibited by ethics.

**3. The nature of scientific thinking**

**31. Inductive thinking**

311. Inductive thinking is used to infer general law from limited numbers of observations.
312. Scientific law via inductive thinking cannot be guaranteed the truth of scientific knowledge.

**32. Deductive thinking**

321. Deductive thinking is used to explain or predict natural phenomena.
322. Scientific explanation is the process of drawing conclusions through premises consisting of general law and initial conditions.
323. Deductive thinking is used to predict an experimental result based on a hypothesis, and to falsify a scientific hypothesis.
324. The confirmation of a hypothesis cannot be logically warranted because the structure of it is fundamentally equivalent to the 'affirmation of the consequent' of the syllogisms.
325. The falsification process is logically possible because the structure of it is the same as the '*modus tollens*' of the syllogism.

**32. Abductive thinking**

331. Abductive thinking is used to generate or invent a new scientific hypothesis to explain new phenomena.
332. Background knowledge takes an important role in abductive thinking.
333. Abductive thinking involves similarity-based reasoning between the background knowledge and new phenomena to be explained.

## IV. Conclusion and Further Studies

In this article, various aspects of the NOS emphasizing in science curriculum, science education reforms and teaching efforts for improving students' understanding the NOS have been reviewed. Then, some features of philosophy of science to obtain implications regarding the nature of scientific thinking and developmental nature of scientific knowledge were summarized. Finally, based on these reviews and summaries, a synthetic list of the NOS has been proposed, consisting of three categories: the nature of scientific knowledge, the nature of scientific inquiry, and the nature of scientific thinking.

As mentioned earlier, this proposed synthetic list of the NOS is not complete. Many other emphases regarding the NOS would be possible. Hopefully, through further studies, many other opinions and stresses about the NOS will be suggested, thus leading to the list of the NOS in this article being revised and refined into a more complete form.

It is hoped that this list of the NOS can provide basic standards for discussing the NOS when teaching the NOS in schools, as well as concrete guidance for developing teaching materials for improving students' understanding the NOS. In the next article, by linking the NOS with scientific inquiry more in detail, new models of scientific inquiry though understanding the NOS will be proposed.

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