한국과학교육학회지, 28권 7호, pp. 759－767(2008. 11)　　J Korea Assoc. Sci. Edu, Vol. 28, No. 7, pp. 759－767(2008. 11)

Teaching Models for Scientific Inquiry Activity through the Nature of Science (NOS)

Jongwon Park*

Chonnam National University, Gwangu, KOREA

Abstract: This article arose from the previous studies, which suggested a synthetic list for the nature of science (NOS), discussed the relationship between the NOS and scientific inquiry and the development of the NOS in the context of scientific inquiry. In this article, for teaching scientific inquiry through the NOS, I proposed three teaching models - reflection, interaction, and the direct model -. Within these teaching models, understanding the NOS is viewed as a prerequisite condition for the improved performance of scientific inquiry. In the reflection model, the NOS is embedded and reflected in scientific inquiry without explicit introduction or direct explanation of the NOS. In the interaction model, concrete interaction between scientific inquiry and the NOS is encouraged during the process of scientific inquiry. In the direct model, subsequent to directly comprehending the NOS at the first stage of activity, students conduct scientific inquiry based on their understanding of the NOS. The intention of this present article is to facilitate the use of these models to develop teaching materials for more authentic scientific inquiry.

Key words: The nature of science, teaching model, authentic scientific inquiry, science teaching.

I. Introduction

Currently, teaching the nature of science (NOS) has become a major component of science education (Hodson, 1988; Matthews, 1994; Lederman, 1999; Hand *et al.,* 1999; Sandoval, 2005; Bell and Lederman, 2003). Consequently, many science educators (McComas & Olson, 1998; Lederman and Abd-El-Khalick, 1998; Ping-Kee Tao, 2003; Bianchini and Colburn, 2000; Lederman *et al.,* 2002) and science curriculums (AAAS, 1994; NRC, 2000; NSTA, 2000; Donnelly, 2001) have emphasized the NOS in teaching science. Recently, Park (2007) proposed a synthetic list consisting of 42 statements describing the NOS based on a comprehensive literature review concerning the NOS. And Park (2008) discussed the relationship between the NOS and scientific inquiry. This discussion was motivated by the need to provide more in-depth study concerning the link between the NOS and scientific inquiry, since these two areas are so closely related to each other (Lederman, 1998; Matthews, 1998; Sandoval, 2005; Schwartz *et al.,* 2004). In Park's discussion, he compared two approaches for teaching the NOS and scientific inquiry; teaching the NOS through scientific inquiry and teaching scientific inquiry through the NOS. In the former case, the primary goal is to improve students' understanding of the NOS by encouraging them to conduct scientific inquiry. Therefore, scientific inquiry is used as a pedagogical tool for enhancing the understanding of the NOS. However, "conducting scientific inquiry in a more authentic way" has an intrinsic value in learning science. Therefore, in the latter case, understanding the NOS is viewed as a prerequisite condition for achieving an improved performance of scientific inquiry.

For the approach of teaching the NOS through scientific inquiry, Park and Kim (2007) developed approximately 40 worksheets. According to Park and Kim, each worksheet was developed in the context of scientific inquiry. Each worksheet identified what kind of scientific knowledge, scientific inquiry skills, and components of the NOS were involved in the process of learning activity. Recently, Park and Kim (2008) applied the developed worksheets to a group of gifted students. In their article (Park and Kim, 2008), they reported that many students showed more interest in the nature of scientific thinking than in

*Corresponding author: Jongwon Park (jwpark94@chonnam.ac.kr)
**Received on 4 August 2008, Accepted on 9 September 2008

specific scientific knowledge or in interesting inquiry activities. They also noted that the students realized that understanding the nature of scientific inquiry was expected to be helpful for conducting their own scientific inquiry.

This article extends the development of the above-mentioned research, by examining the comprehensive review of the NOS and the suggested synthetic list of the NOS (2007). This article is also concerned with the discussion about the link between the NOS (Park, under review), and with the development of worksheets for teaching the NOS in the context of scientific inquiry (Park & Kim, 2007).

The main concern of this article is related to the teaching of scientific inquiry through the NOS. In this article, three models are proposed and compared. Examples of teaching materials for each model are suggested, and various features of each model are discussed.

II. Models for Scientific Inquiry through Understanding the NOS

The three models of scientific inquiry through the NOS include ‘the reflection model’, ‘the interaction model’, and ‘the direct model’. These models vary according to the level of appearance and degree of detail of the NOS during scientific inquiry. In the reflection model, the NOS is embedded and reflected in scientific inquiry implicitly. However, an explicit introduction, instruction, or explanation of the NOS is not provided during scientific inquiry. Nonetheless, scientific inquiry activities are designed to reflect the main characteristics and aspects of the NOS.

In the interaction model, concrete interaction between scientific inquiry and the NOS is specified when conducting scientific inquiry activities. Therefore, when performing scientific inquiry, students are asked to investigate and discuss which aspects of the NOS are related to their inquiry.

In the direct model, the NOS is directly introduced and instructed at first. Specifically, after comprehending the NOS at the first stage of activity, the students conduct the scientific inquiry based on their understanding the NOS.

This article does not attempt to provide an empirical justification for the proposed models of scientific inquiry through understanding the NOS. However, ideas and guidance are suggested for the ongoing implementation and application of scientific inquiry in a more authentic way in schools. Such theoretical suggestions are, naturally, based on studies previously mentioned (Park 2007; Park, under review; Park & Kim, 2007; Park & Kim, under review). It is therefore intended that the proposed models in this article could be used for developing and designing concrete teaching and learning activities or materials in a more practical way.

1. The Reflection Model

In this model, students are not directly required to understand the NOS but are required to conduct scientific inquiry designed to reflect the features of the NOS. Specifically, in the process of scientific inquiry, the NOS is not explicitly introduced and explained to students. However, the main ideas and characteristics of the NOS are reflected and embedded in the inquiry activity (Fig. 1).

For example, a scientific inquiry activity may be designed to encourage students to explore the change in scientific knowledge by varying the prior assumptions or initial conditions related to scientific knowledge. In this activity, it is expected that students will experience the nature of scientific knowledge (e.g., scientific knowledge is tentative and subject to change) while performing their scientific inquiry. For instance, Jansen and Voogt (1998) designed a teaching plan for learning about the immune system in a biology class by reflecting on the developmental nature of scientific knowledge through the activities of suggesting, applying, testing (checking), and revising a hypothesis. Contrary to the traditional approach, where the teacher introduces a main theory at first, Jansen and Voogt present a problem from the outset (‘How can a virus be

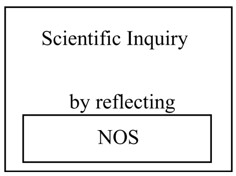


Fig. 1 *Reflection Model*

rendered harmless?'). They then allow students to suggest a hypothesis to solve the problem ('There may be an 'eating cell' that ingests the virus.'). The students then check the error or limit of the hypothesis (Can the eating cell also digest the body's own cell?'), propose new problems ('How can an eating cell discriminate between a body's own cell and a virus?'), and revise the original hypothesis (The body's own cell carries a label on the surface, then, by recognizing the label, the eating cell does not ingest the body's own cell'), or suggest a new hypothesis. New problems can then be generated (e.g., 'A virus can imitate this label'), and successive processes of refinement and articulation of the hypothesis can be continued. Here, instead of directly introducing and explaining the developmental nature of scientific knowledge, scientific inquiry has been designed so that students can examine and experience the process of generation, revision, and development of ideas.

In the reflection model, the important aspect becomes the question of how to immerse the features of the NOS into scientific inquiry. As a result, the model inquires into how students can be facilitated to perform authentic scientific inquiry by experiencing aspects related to the NOS rather than by directly understanding the features of the NOS.

Fig. 2 shows an example of the use of the reflection model. In order to determine the density of liquid, students are usually required to measure various volumes and masses of liquid and to then directly calculate the ratio of mass (M) and volume (V) of the liquid. However, in an actual scientific inquiry, scientists would search for and detect general patterns or regularities among very complex data and phenomena. Activities 2 and 3 in Fig. 2 indicate how students learn experientially by following a similar process to that used in actual scientific inquiry, where they are encouraged to experience the process of finding a general pattern (as an inductive process) among various complex outcomes, including M+V, M-V, M×V, and M÷V, rather than to simply calculate the density of a liquid by a direct one-way step.

In actual scientific research, scientists would also identify and describe the detailed situations and conditions that exist when data is obtained (such as,

1. Measure the mass of 20 ml, 40 ml, 60 ml, and 80 ml of a given liquid (e.g., ethyl alcohol).

2. Using your measurements, complete the following table.

	V: Volume (ml)	M: Mass (g)	M+V	M-V	M×V	M÷V
1	20					
2	40					
3	60					
4	80					

3. Find any general patterns from the above table.

4. Can the general patterns found in Activity-3 be changed if the temperature of liquid is varied? If so, then do you need to describe the temperature of the liquid when you present the general pattern found in Activity-3. If there are other conditions which can affect the general pattern found in Activity -3, describe them also.

Fig. 2 *A sample of simple scientific inquiry using the reflection model*

atmosphere or temperature). These aspects are closely related to the tentative nature of scientific knowledge. To imitate this in the learning environment, activity 4 is proposed so that students are made aware of the fact that scientific knowledge should be presented with initial conditions, assumptions, and auxiliary hypotheses.

In this activity, any direct explanations about the nature of induction and the tentative nature of scientific knowledge are not given. However, this activity is designed to improve the students' inquiry activity by reflecting on the features of the NOS.

Bell and Linn (2000) and Sandoval and Reiser (2004) have documented their research on this reflection model. By utilizing rival theories so that students would integrate their ideas, Bell and Linn (2000) reflected on the nature of scientific knowledge, that is, while scientific knowledge depends on empirical and theoretical evidence, it can still be interpreted in a variety of ways, and scientific inquiry is conducted cooperatively. Sandoval and Reiser (2004) asked students to use evidence to develop a scientific explanation by reflecting on the nature of scientific knowledge (e.g., scientific knowledge has supporting evidence and evolves through successive articulation and refinement), and the nature of scientific inquiry (e.g., experimental data is subject to the inclusion of anomalous data.).

The characteristics of the reflection model are considered to be similar to the implicit teaching efforts for understanding the NOS by conducting scientific inquiry. This is because researchers designed their scientific inquiry based on the sprit of the NOS. For example, the work of Cartier and Stewart (2000) was based on the nature of scientific knowledge (e.g., scientific knowledge is tentative and depends on theoretical backgrounds as well as empirical data.). They asked students to first construct a simple model, to then apply it to other phenomena, and then to revise it based on anomalous data. However, even though the teaching efforts of Cartier and Stewart are similar to the model proposed in this present article, they differ in that their intention was to improve the understanding of the NOS, rather than to provide an authentic performance of scientific inquiry.

2. The Interaction Model

It has been reported that many implicit teaching efforts aimed at enhancing students' understanding of the NOS have showed insignificant improvements in their understating the NOS (Abd-El-Khalick & Lederman, 2000). In this case, the main ideas of the NOS using the reflective model may also not affect the performance of students' scientific inquiry. And even though students have a sound understanding of the NOS, if they do not realize the relationship between the NOS and their scientific inquiry, then they may not necessarily be able to apply this understanding of the NOS to the process of conducting scientific inquiry. It is therefore often required to encourage students to be aware of which aspects of the NOS are important in and related with their scientific inquiry and how understadning the NOS can assist their inquiry activities (Fig. 3).

In order to encourage students to achieve this, they can be asked during the inquiry activity to answer questions that remind them of the features of the NOS, to discuss which aspects of the NOS are related to their activities, or to respond to the checklist describing the relevant contents of the NOS. Carey, Evans, Honda, Jay, and Unger (1989) developed inquiry activities for helping students to recognize

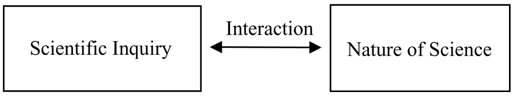


Fig. 3 *The Interaction Model*

the aspects of the NOS. An example of such an activity would be a teacher-led discussion focused on scientific knowledge as explanatory human constructs and the use of experiments to test ideas rather than merely discovering them.

Julie Gess-Newsome (2002), in a pre-service teacher's program, used such an inquiry activity by asking teachers to discuss features of the nature of scientific inquiry while conducting scientific inquiry about a pendulum. While they were finding a way to alter the period of the pendulum by varying the release point, mass, and length, the teachers discussed and defined the terms of the variables and the controlled experiment. When the teachers predicted the change of the period of the pendulum before testing their results, they differentiated and synthesized the terms including guess, prediction, inference, and hypothesis. While the teachers interpreted the relationships between variables, they also introduced definitions and examples of laws and theories. In this activity, the intention to realize an active interaction between conducting scientific inquiry and recognizing the nature of scientific inquiry was therefore achieved.

While the basic purpose of the above study was to assist students to develop an understanding of the nature of scientific inquiry, this type of activity can be used to enhance students' performance of scientific inquiry through understanding the NOS. For example, when students try to suggest hypotheses from their observations, their hypothesis generation activity may be improved if we can help students to understand the nature of a scientific hypothesis (Park, 2006). According to Park (2006), to be a good scientific hypothesis, it should be testable and give explanation rather than description. And scientific hypothesis can be generated using background knowledge and past experience by recognizing the similarity between the phenomena to be explained and his/her background knowledge. Therefore, he suggested a model of 'similarity based reasoning' which can be used as a thinking tool to generated new scientific hypothesis. Fig. 4 shows an activity designed for this purpose.

Toth *et al.* (2002) requested students to reflect on the way they conducted their scientific inquiry by using a scientific inquiry rubric (checklist), which listed aspects of the NOS that are related to methods

1. Describe the observational result when a magnet drops inside an aluminum pipe standing vertically.

2. Ask a "why" question about your observation.
3. Suggest a hypothesis (an answer to your "why" question (2)), which can explain your observation.
4. When suggesting a hypothesis, you need to check whether your hypothesis meets the following three conditions:
   (1) A hypothesis should be testable. Discuss the meaning of the term, 'testable'.
   (2) A hypothesis does not describe but explains your observation. Discuss the difference between description and explanation.
   (3) To suggest a new hypothesis, background knowledge or past experiences, similar to your observation, can be useful. Discuss similar aspects between the following 3 experiments and your observation.

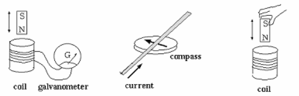


Fig. 4 *Generating hypothesis based on the interaction with the NOS*

of scientific inquiry. When the students were evaluating information they had collected, they were asked whether they had considered multiple hypotheses, whether they had used data against as well as for each hypothesis, and whether they had warranted their generalizations, etc. Even though not all the contents of this rubric were concerned with the NOS, this type of strategy can be used for the interaction model.

Fig. 5 shows a simple example of scientific inquiry using a checklist. Fig. 5 includes the simple activity of predicting a phenomenon. According to Hempel (1965), and Park and Han (2002), scientific prediction is a deductive logical conclusion based on two premises that consist of general laws and initial conditions. Therefore, if students are encouraged to realize that searching relevant general laws and describing the initial conditions of phenomena is essential for predicting a result, and that deductive logical thinking is useful for prediction, this guide may help students in their predicting activity. Specifically, this activity aims at helping students' inquiry activity by reminding them of the nature of scientific prediction. Certainly, in other actual scientific inquiries, further activities may need to be employed, such as generating inquiry problems, identifying variables, or designing an experiment to test a hypothesis. Therefore, in each activity, a suitable checklist needs to be provided in order to guide students towards a more authentic inquiry.

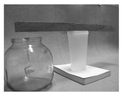
Scientific Inquiry Activity	
1. Put the long wood rod across the top of the cup. 2. If you bring a plastic pipe rubbed by fur closely to the right end of the wood rod, what will happen to the electroscope? Describe your prediction. 3. Before an observation, compare your prediction with predictions of others. Which predictions are the most plausible? 4. Observe the phenomena and compare your observation with your prediction.	
Guidelines for above activity	Check
Guide 1: My prediction started from general laws and theories.	( )
Guide 2: I described the initial conditions related to the observation.	( )
Guide 3: To predict the phenomena, I used deductive logic.	( )

Fig. 5 *Simple activity for prediction using a checklist*

When using the interaction model, students are required to have a basic understanding of the NOS, because direct and explicit explanations about the NOS are not provided. Therefore, the interaction model can be applied when students have already studied the basic features of the NOS in the first chapter of the science textbook.

3. The Direct Model

This model consists of two steps. The first step provides concrete and explicit activities for enhancing students' understanding of the NOS, while in the second step scientific inquiry activities are conducted, as shown in Fig. 6. The activities of these two steps are, of course, closely related to each other.

In some cases, students have prior ideas before they observe certain natural phenomena. It can therefore be expected that students' observational activities may be affected by their prior ideas. In fact, Park and Kim (2004) observed that nearly half of the students involved in their learning activity distorted their observations according to their prediction. In such a case, for the first step in scientific inquiry, students would need to understand the nature of scientific observation, that is, theory-ladenness of scientific observation.

It is important to note that this model assumes that by providing direct and didactic explanations, the teacher will not necessarily assist the students to understand the NOS in the first step. Rather, this

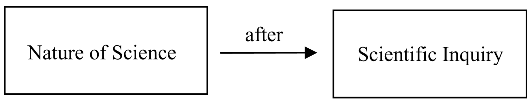


Fig. 6 *The Direct Model*

I. The first step

1. In the following figures,

(a) Which side has a spot in the first figure?

(b) Describe what you see in the second and the last figure.

(c) Do you think that others' observations are the same as yours? Do you think that all observations are objective and the same?

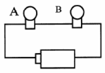
2. In the following X-ray photography,

(a) Describe what you observe.

(b) Are your observations the same as the doctor's observation or are they different? Explain the reason. ________________________

3. Summarize the features of the observation.

II. The second step



1. Predict which bulb will be brighter.

2. Connect the switch and observe the brightness of the bulbs. Which bulb is brighter?

3. Does your observation agree with your prediction or not?

3. Fill out the following table, and discuss with peers the difference between observations.

	You	Peer 1	Peer 2	Peer 3
Prediction				
Observation				

4. Do you think that an observer's prediction can affect an actual observation?

Fig. 7 *Example of Activity based on the direct model*

model requires that this understanding be acquired through the provision of opportunities for students to experience and explore the features of the NOS. Fig. 7 shows an example of an activity based on this direct model.

In the first step shown in Fig. 7, the students recognize that observation can differ depending on the observer and that it can be affected by the observer's background knowledge. Subsequently, in the second step, students are expected to make more authentic scientific observations by comparing their observations with their prediction and by comparing their peer's observations and predictions.

The typical Ohm's Law experiment for obtaining the relationship between electric current and voltage can be used to provide an example of an activity using this model. In this experiment, various scientific inquiry skills are required such as, measuring, making and interpreting a graph, and drawing a general conclusion. This activity also involves several aspects related to the NOS. For example, when students are interpreting the relationship between electric current and voltage, they need to be aware of the nature of scientific knowledge, and to understand that 'scientific knowledge often indicates a causal relationship between variables'. Therefore, in order to help students'

1. Mr. Park worked hard yesterday and has caught a cold today. Which of these is a cause and which is an effect?
2. In the representation, y=ax, which is the dependant variable and which is the independent variable?
3. Discuss the relationships between dependent and the cause, and between independent variables and the effect.
4. In Newtonian mechanics, the acceleration of a body is the result of an acting force on a body. Therefore, between the two expressions, F=am and a=F/m, which one is a more appropriate form to represent the relationship between cause and effect?

Fig. 8 *The first step for understanding the causal relationship between variables*

inquiry activity, an activity that encourages students to understand the causal structure of scientific law needs to be conducted before the Ohm's Law experiment in the second step of the direct model, as shown in Fig. 8. Specifically, in the second step, a discussion about the expression that concerns the causal relationship between electric current and voltage can help students develop their understanding of Ohm's Law in a more authentic way.

In the first step of the direct model, many teaching methods and strategies can be applied, which are used in an explicit approach for enhancing students' and teachers' understanding of the NOS. Fore example, Lederman and Abd-El-Khalick (1998) developed various activity-based explicit teaching ideas for the instruction of the NOS. Akerson *et al.* (2000) observed that, when using these ideas, many undergraduate and graduate pre-service teachers improved their understanding of the NOS. For example, students were asked to answer a range of questions related to the illustration shown in Fig. 9. These questions included 'What do you observe?', 'Can you see the birds?', 'How can you tell that these tracks are left by birds?' and 'What do you infer (from your observation)?' This activity helped the students to

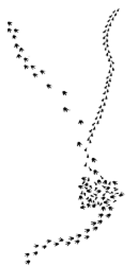


Fig. 9 *Figure used by Lederman and Abd-El-Khalick (1998)*

realize the difference between observation and inference by experiencing that a range of results could be drawn from the same evidence.

Here, the important point is that the content in the first step related to the NOS should be closely related to the scientific inquiry in the second step. Therefore, exploring and understanding the features of the NOS in the first step should help students to perform scientific inquiry in a more authentic way.

Ⅲ. Conclusion and Further Studies

Scientific inquiry may be viewed as an essential learning tool or strategy for enhancing scientific literacy, empowering conceptual understanding, helping the comprehension of the NOS, and encouraging scientific attitude and interests. Therefore, considering how we can help students to conduct scientific inquiry in a more authentic way must be one of the main goals of science education. The teaching models proposed in this study are directed towards improving the quality of scientific inquiry by reflecting the spirit of the NOS. The three proposed models outlined in this article are categorized according to the degree of explicitness with which they treat the NOS during the process of scientific inquiry.

Because there is no explicit and direct introduction and teaching of the NOS in the reflection model, this model can be applied to revise ordinary scientific inquiry activities in science textbooks. As mentioned earlier, many scientific inquiry activities in science textbooks need to be further articulated because they are either not designed to consider the NOS or the aspects of the NOS are treated inaccurately (Hodson, 1988; Chinn and Malhotra, 2002). By merging the features of the NOS into scientific inquiry, it is expected that students will be able to conduct scientific inquiry activity in a manner that more closely resembles actual scientific research and is more suitable to the spirit of science.

In the case of the interaction model, more active interventions are used, such as providing guidance, a checklist, or comments for reminding students of the features of the NOS related to their scientific inquiry activity. These interventions should certainly be designed to help students conduct inquiry activities in a more authentic way. However, because the interaction model does not provide direct teaching and detailed explanations of the NOS, students are required to have a basic understanding of the NOS before performing scientific inquiry. Therefore, the interaction model is adequate when textbooks that provide a first chapter related to the learning of the NOS. Learning the NOS in the first chapter does not usually guarantee the active link between features of the NOS and the performance of scientific inquiry included in later chapters of the textbook. Then, the interaction model can be used to encourage students to recall, realize, and relate aspects of the NOS to their inquiry activities.

The direct model basically involves the sequential connecting of the NOS to scientific inquiry. In this model, two goals coexist: to explicitly understand the NOS and to conduct scientific inquiry. To achieve this, many explicit teaching materials, ideas, and strategies for improving the students' understanding of the NOS can be utilized for the first stage of the direct model. This model would be appropriate where there is no independent chapter in the textbook for teaching the NOS, and where teachers require that their students directly understand the features of the NOS.

This article provides a foundation for a larger project concerning the teaching of scientific inquiry in schools. Therefore, more concrete activity materials that use these three models for scientific inquiry through the NOS, need to be developed and implemented for use in actual teaching in schools. In order for these activities to be applied in existing learning situations, concrete teaching and learning materials may be required to have the traditional format of a 40-50 minute activity in the usual school context. Alternatively, these activities may be project-based, requiring several weeks or months. When developing a new scientific inquiry activity through the NOS, we also need to consider various conditions such as the students' intellectual levels, their interests, motivation, and background knowledge, etc. When implementing these models, it is also required to investigate, analyze, and understand students' actual responses and mental processes. Students may act differently than the way we expect. Specifically, they may have different ways of recognizing the goal of an inquiry activity, or they may proceed with unexpected thinking processes from what we assume, and may be interrupted by unknown limiting factors. Therefore, based on these studies, the three models outlined in this article may be refined and modified,.

In addition to the variety of factors that influence students' responses, factors influencing teachers' actions should also be considered in the effective teaching of scientific inquiry. In some circumstances, science teachers may not have an appropriate understanding of the NOS, or they may not have concrete examples or ideas for teaching the NOS. Alternatively, they may not believe that there is a special need to apply a new approach, even though they may have a relevant understanding of the NOS and may have relevant ideas for the teaching of the NOS. In order to achieve a successful implementation of these models, teachers are required to have content knowledge, pedagogical content knowledge, and an enthusiasm for teaching. Therefore, we also need to ensure that new models of scientific inquiry are utilized in the teachers' in-service training program. More authentic teaching and learning of scientific inquiry may then be expected.

References

American Association for the Advancement of Science (AAAS) (1994). *Project 2061: Science for All Americans.* Oxford University Press, New York.

Abd-El-Khalick, F., and Lederman, N.G. (2000). Improving science teachers' conceptions of nature of science: a critical review of the literature. *International Journal of Science Education*, 22, 665-701 .

Akerson, V.L., Morrison, J.A., and McDuffie, A.R. (2006). One course is not enough: Preservice elementary teachers' retention of improved views of nature of science. *Journal of Research in Science Teaching*, 43(2), 194-213.

Bell, P., and Linn, M.C. (2002). Beliefs about science: how does science instruction contribute? In: B.K. Hofer, and P.R. Pintrich (eds), *Personal Epistemology: The Psychology of Beliefs about Knowledge and Knowing* (p. 321), Lawrence Erlbaum Associates, Publishers: London.

Bel,l R., and Lederman, N.G. (2003). Understandings of the nature of science and decision making on science and technology based issues. *Science Education*, 87, 352-377.

Bianchini, J., and Colburn, A. (2000). Teaching the nature of science through inquiry to prospective elementary teachers: A tale of two researchers. *Journal of Research in Science Teaching*, 37(2), 177-209.

Carey, S., Evans, R., Honda ,M., Jay, E., and Unger, C. (1989). An experiment is when you try it and see if it works: A study of grade 7 students' understanding of the construction of scientific knowledge [Special issue]. *International Journal of Science Education*, 11, 514-529.

Cartier, J.L., and Stewart, J. (2000). Teaching the nature of inquiry: Further developments in high school genetics curriculum. *Science and Education*, 9, 247-267.

Chinn, C.A., and Malhotra, B.A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating in inquiry tasks. *Science Education*, 86, 175 - 218.

Donnelly, J. (2001). Contested terrain or unified project? 'The nature of science' in the National Curriculum for England and Wales. *International Journal of Science Education*, 23(2), 181-195.

Hand, B., Prain, V., Lawrence, C., and Yore, L.D. (1999). A writing in science framework designed to improve science literacy. *International Journal of Science Education*, 10, 1021-1036.

Hempel, C.G. (1965). *Aspects of Scientific Explanation*. The Free Press, New York.

Hodson, D. (1998). Is this really what scientists do? In: J. Wellington (ed), *Practical work in school science: Which way now?* (p. 93), Routledge, London.

Jensen, F., and Voogt, P. (1998). Learning by designing: A case of heuristic theory development in science teaching. In: W.F. McComas (ed), *The nature of science in history of science in science education: Rationales and strategies* (p. 151), Kluwer Academic Publishers, The Netherlands, Dordrecht.

Julie Gess-Newsome. (2002). The use and impact of explicit instruction about the nature of science and science inquiry in an elementary science methods course. *Science & Education*, 11, 56-67.

Lederman, N.G. (1998). The state of science education: subject matter without context. Electronic *Journal of Science Education* 3(2). In: http://unr.edu/homepage/jcannon/ejse/lederman.html. Cited 12 March 2007.

Lederman, N.G., and Abd-El-Khalick, F. (1998).

Avoiding de-natured science: Activities that promote understandings of the nature of science. In: W.F. McComas (ed), *The nature of science in history of science in science education: Rationales and strategies* (p. 83), Kluwer Academic Publishers, The Netherlands, Dordrecht.

Lederman, N.G. (1999). Teachers' understanding of the nature of science and classroom practice: factors that facilitate or impede the relationship. *Journal of Research in Science Teaching*, 36, 916-929.

Lederman, N.G, Abd-El-Khalick, F., Bell, G.L., and Schwartz, R.S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, 39, 497-521.

Matthews, M.R. (1994). *Science Teaching: The Role of History and Philosophy of Science*. Routledge, New York.

Matthews, M.R. (1998). In defense of modest goals when teaching about the nature of science. *Journal of Research in Science Teaching*, 35, 167-174.

McComas, W.F., and Olson, J.K. (1998). The nature of science in international science education standards documents. In: W.F. McComas (ed), *The Nature of Science in Science Education: Rationales and Strategies* (p. 41), Kluwer Academic Publishers, Dordrecht.

National Research Council [NRC] (2000). *Inquiry and the national science education standards.* In: http://www.nap.edu/openbook.php?record_id=9596&page=1. Cited 10 January 2008.

National Science Teachers Association [NSTA] (2000) *NSTA position statement: The nature of science.* In: http://www.nsta.org/about/positions/natureofscience.aspx. Cited 10 january 2008.

Park, Jongwon. (2007). 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-. *Journal of the Korean Association for Science Education*, 27(2), 153-167.

Park, Jongwon. (2008). Discussions for linking the Nature of Science (NOS) with Scientific Inquiry. *Journal of the Korean Association for Science Education*, 28(7), 749-758.

Park, Jongwon., and Kim, Doohyun. (2007). *Development of comprehensive learning materials for the understanding nature of science in the context of scientific inquiry.* Report No. KRF-2006-721-B00029. Korea Research Foundation, Seoul.

Park, Jongwon., and Kim, Doohyun. (2008). Development of Teaching Materials for the Nature of Science and Pilot Application to Scientifically Gifted Students. *Journal of the Korean Association for Science Education*, 28(2), 169-179.

Park, Jongwon., and Han, Sooja. (2002). Deductive reasoning to promote the change of concept about force and motion. *International Journal of Science Education*, 24(6), 593-610

Park, Jongwon., and Kim, Ikgyun. (2004). Classification of students' observational statements in science. In: R. Nata (ed), *Progress in Education*, Vol.13. (p. 139), Nova Science Publishers, Inc. New York.

Park, Jongwon. (2006). Modelling Analysis of Students' Processes of Generating Scientific Explanatory Hypotheses. *International Journal of Science Education*, 28(5), 469-489.

Ping-Kee Tao. (2003). Eliciting and developing junior secondary students' understanding of the nature of science through a peer collaboration instruction in science stories. *International Journal of Science Education*, 25(2), 147-171.

Sandoval, W.A. (2005). Understanding students' practical epistemologies and their influence on learning through inquiry. *Science Education*, 89, 634-656.

Sandoval, W.A., and Reiser, B.J. (2004). Explanation-Driven inquiry: integrating conceptual and epistemic scaffolds for scientific inquiry. *Science Education*, 88, 345-372.

Schwartz, R.S., Lederman, N.G., and Crawford, B.A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education*, 88, 610-645.

Toth, E.E., Suthers, D.D., and Lesgold, A. (2002). "Mapping to know": The effects of representational guidance and reflective assessment on scientific inquiry. *Science Education*, 86, 264-286.