EXAMINING THE EFFICACY OF AN EXPLICIT AND REFLECTIVE COURSE ON PRESERVICE SECONDARY SCIENCE TEACHERS' CONCEPTIONS OF NATURE OF SCIENCE

The purpose of this study was to examine the relative efficacies of explicit and reflective instruction using targeted activities and readings in a graduate-level nature of science (NOS) course for preservice secondary science teachers. Seventeen preservice teachers participated in this study. Participants responded to an open-ended questionnaire designed to assess their conceptions of NOS before and after the course intervention. Following the administration of the questionnaires a sample of participants was interviewed to validate their responses to the open-ended questionnaire. Interview data, in addition to artifacts collected during the course, were used to examine links between changes in NOS conceptions and course activities and readings. The data reveals an overall pattern concerning the relative degree of change of NOS conceptions over the course intervention and the number of explicit and reflective activities and readings. A combination of targeted activities and readings taught in an explicit and reflective way most directly affected the participants' conceptions of NOS. Those aspects of NOS taught using targeted readings alone showed less development over the course. The findings provide further understanding of the link between NOS pedagogy and preservice secondary science teachers' development of NOS conceptions.

Ron Gray, Oregon State University
Nam-Hwa Kang, Oregon State University

Introduction

The nature of science (NOS) has long been advocated for as an essential element of secondary science education. It occupies a central role in the various reform efforts, such as *Project 2061* (American Association for the Advancement of Science [AAAS], 1990, 1993) and the *National Science Education Standards* (National Research Council, 1996) and has been thoroughly studied by science education researchers over the past several decades (Lederman, 2007). NOS has been defined as the epistemology of science, a way of knowing, or the values and beliefs fundamental to the development of scientific knowledge (Lederman, 1992). On an academic level defining the components of NOS has been contested. Schwartz and Lederman (2002) state, "there is not a single 'nature of science' that fully describes all scientific knowledge and enterprises – various representations of NOS have been affirmed by historians, philosophers of science, science educators, and others" (p. 207). However, some common tenets of NOS do exist at a K-12 level (Lederman & Lederman, 2004; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). Common NOS descriptions often include characteristics such as empirically-based, tentative, subjective, creative, unified, and culturally and socially embedded. Individuals with sophisticated understandings of NOS can recognize and distinguish between observations and inferences as well as facts, laws, and theories and are able to utilize scientific processes, such as observation, classification, and prediction, in a flexible manner during scientific investigations.

If an adequate understanding of NOS is our goal for students, then teachers' sophisticated understanding of NOS is a necessary though not sufficient condition (Lederman, 1992, 1998). Studies have shown that teachers often hold positivistic views of science which, in turn, are communicated to their students (e.g., Gess-Newsome, 1999). This positivistic view of science limits a teacher's ability to develop and implement lessons that will affect their students learning of NOS as well as the content of science (Kang & Wallace, 2005). Therefore, it is important for teachers to understand NOS before they can effectively address it in their classroom (Bartholomew, Osborne, & Ratcliffe, 2004). Furthermore, teachers' understanding of NOS should go beyond being able to define and assess NOS goals in the classroom; they should be able to develop sound pedagogical practices related to NOS to be effective in student learning (Bartholomew et al., 2004).

In an effort to prepare teachers with sophisticated knowledge of NOS, there have been studies about preservice science teachers' learning of NOS as well as pedagogical approaches. In terms of NOS pedagogy for preservice teachers, three approaches have been used and studied (Lederman, 1992, 1998):

Historical approach. An historical approach can be taken in which NOS is taught through the incorporation of case studies in the history of science in order to enhance students' views of NOS. While some studies do report significant changes in NOS understandings (e.g. Lin & Chen, 2002), the results are inconclusive (Khishfe & Abd-El-Khalick, 2002).

Implicit approach. The second approach previously studied is the implicit approach in which curricula assumes that students will enhance their NOS conceptions simply by participating in an inquiry-based activity (Lederman & Abd-El-Khalick, 1998; Schwartz, Lederman, & Crawford, 2004). In this approach no explicit attention is paid to NOS. Rather, it is assumed that student understandings will develop as a natural consequence of engaging in the activity (Schwartz et al., 2004). Research has shown, however, that students do not develop more sophisticated NOS conceptions as a by-product of engaging in inquiry-based activities (Khishfe & Abd-El-Khalick, 2002).

Explicit-reflective approach. The explicit approach views NOS as a cognitive objective (Lederman, 1998) that is explicitly planned for in a way that draws students' attention to NOS. This means deliberately designing lessons to address specific components of NOS. Thus, while an explicit approach to teaching NOS engages students in activities, it also involves purposeful instruction of NOS (Schwartz & Lederman, 2002). Of equal importance is reflective teaching which helps students make connections between the activities and the targeted components of NOS (Khishfe & Abd-El-Klahick, 2002). When implementing this approach, the instructor explicitly introduces the students to targeted NOS aspects and then provides them opportunities to reflect on these aspects during and after the activity. In addition, Lederman and Lederman (2004) explain that while some students may reflect on an instructional activity independently, the most effective way to ensure reflection for all students is to develop questions and carefully plan their placement within the activity to elicit reflective instruction.

Research suggests that NOS instruction is most effective when it is both explicit and reflective in character. For instance, Abd-El-Khalick (2001) and Abd-El-Khalick and Akerson (2004) used an explicit, reflective approach to teach NOS to prospective elementary teachers. The authors reported significant improvement in multiple aspects of NOS and concluded that the explicit, reflective approach to instruction was successful. Khishe & Abd-El-Khalick (2002) emphasize that:

> the term 'explicit' … does not refer to didactic or explicit teaching strategies, but is meant to highlight the notion that NOS understandings are cognitive instructional outcomes that should be intentionally targeted and planned for in the same manner that abstract understandings associated with high-level scientific theories, such as evolutionary theory and atomic theory are intentionally targeted. (p. 555)

The purpose of this study is to examine the relative efficacies of explicit and reflective instruction using targeted activities and readings in a graduate-level NOS course for preservice secondary science teachers. This study is part of a larger study that examines the development of student conceptions of NOS over the course of a teacher preparation program.

Explicit and Reflective Instruction in the Graduate Level NOS Course

The NOS course was a four-week intensive summer course consisting of fifteen 3-hour class sessions, 12 of which were applicable to the current study. The overall objective of the course was: (a) to introduce the concept of NOS with the explicit intent to further develop preservice teachers' conceptions of science, (b) to provide experience with inquiry-based activities that explicitly address NOS, and (c) to explicitly address the teaching of NOS in the K-12 science classroom. The purpose was for the participants to gain an understanding of NOS consistent with the current reform documents. In particular, the aspects of NOS highlighted in Science for All Americans ([AAAS], 1990) were used as the framework for the course as they best represented the state and local standards the preservice teachers would be expected to follow in their teaching.

Each session the preservice teachers were assigned readings and reflective journals to achieve the course objectives (Table 2). During the sessions, the students discussed the readings in regards to targeted aspects of NOS and participated in activities designed to address NOS conceptions. Activities included "the Cube activity" (National Academy of Sciences [NAS], 1998), "Tricky Tracks" ([NAS], 1998), "Dino Facts" (Scotchmoor, 1997), and "The Great Fossil Find" (Randak & Kimmel, 1998), which are described in detail below. While it is possible to use these activities and readings to explicitly target many aspects of NOS, in the context of the course each addressed certain aspects of NOS as noted in Table 3. In all discussions and activities, the instructor made explicit references to relevant aspects of NOS and provided reflective questions targeting those aspects.

In conjunction with explicit and reflective instruction, historical examples were utilized to describe and reinforce targeted aspects of NOS. Pertinent aspects of the philosophy of science were also discussed including a comparison of the views on science of Francis Bacon, Karl Popper, and Thomas Kuhn. A modified version of the philosophy of science card exchange activity (Cobern & Loving, 1998) introduced the relevant philosophical ideas discussed in the course. This activity allowed explicit discussion and reflection on a wide variety of philosophical stances concerning science. Near the end of the course, the topic of evolution was examined as a contextualized example of NOS pedagogy. Students in the course wrote daily reading journals, a summative essay on their views of NOS in the context of science teaching, and a science-in-action book report detailing major NOS themes present in scientific research described in popular accounts (e.g., James Watson's *The Double Helix*), all of which were utilized for the current study.

Course Activities

The activities utilized in the course were chosen to highlight specific aspects of NOS (Table 3). Those familiar with these activities will recognize that each could have been targeted toward other aspects of NOS as well. However, only those aspects that were taught in an explicit and reflective way during the course are shown.

Cube activity. The cube activity is a common activity most recently replicated in the National Academy of Sciences publication *Teaching Evolution and the Nature of Science* (1998) and was used as the first NOS activity in this course. In the first portion of the activity the instructor uses a numbered cube to involve students in asking the question "what is on the unseen bottom of the cube?" The students then propose an explanation based on their observations. Then the instructor presents the students with a second cube and asks them to use the available evidence to propose an explanation for what is on the bottom of this cube.

While this activity can be used to target a range of NOS understandings, it was explicitly targeted toward Diversity of Scientific Thinking ("What discoveries in science have utilized this approach?", "How does this compare with 'the' scientific method?"), Science & Certainty ("How certain is your hypothesis?", "Can you be 100% certain of something you cannot observe yourself?"), Cooperation & Collaboration ("What were the advantages of working as a group in this activity?", "Did your partners' differing backgrounds influence the process?"), and Analysis & Interpretation of Data ("What background knowledge did you and your group bring to the activity that allowed you to come to the hypothesis you did?", "How does a scientist's background influence their interpretation of data?"). The activity and discussion lasted about an hour and a half.

Tricky Tracks. The Tricky Tracks activity is a classic activity in geology education and has been around for nearly five decades. It was most recently published in *Teaching Evolution and the Nature of Science* ([NAS], 1998) as well. In this activity, students observe and interpret "fossil footprint" evidence. From the evidence, they are asked to construct defensible hypotheses or explanations for events that took place in the geological past.

This activity was explicitly targeted toward Diversity of Scientific Thinking ("What scientific skills were used in forming your hypothesis?", "How does this compare with 'the' scientific method?"), Science & Certainty ("How certain is your hypothesis?", "How certain can you be of an event that occurred in the past?"), Cooperation & Collaboration ("What were the advantages of working as a group in this activity?", "Do you think different groups of scientists with differing knowledge backgrounds would come to the same conclusions with this data?"), and Analysis & Interpretation of Data ("What background knowledge did you and your group bring to the activity that allowed you to come to the hypothesis you did?", "How does a scientist's background influence their interpretation of data?"). The activity and discussion lasted about forty-five minutes.

Dino Facts. The Dino Facts activity (Scotchmoor, 1997) is based upon work done by the paleontologist Jack Horner and other associates of The Museum of the Rockies in Bozeman, Montana. Data from this research has been used to theorize about the behavior of dinosaurs in that area. In the activity, groups of students are given envelopes containing strips of paper, each with an observation made during the field observations in Montana. The data focuses on the relationship between three Cretaceous-era dinosaur species. The students are asked to group the data together to make inferences about the dinosaurs' behaviors. This process offers a glimpse into paleontological fieldwork.

As above, this activity was explicitly targeted toward Diversity of Scientific Thinking ("This is not an experimental science. What processes and skills are necessary to do this work?", "Is this a good example of 'the' scientific method?"), Science & Certainty ("How certain are your inferences?", "How certain can you be of an event that occurred in the past?"), Cooperation & Collaboration ("What were the advantages of working as a group on this activity?", "If you could form an expert group to analyze this data, what specific backgrounds would you look for?"), and Analysis & Interpretation of Data ("What background knowledge did you and your group bring to the activity that allowed you to come to the hypothesis you did?", "How does a scientist's background influence their interpretation of data?"). The activity and discussion lasted about an hour and a half.

The Great Fossil Find. Similar to the Dino Facts activity, the Great Fossil Find (Randak & Kimmel, 1998) focuses on the process of paleontological fieldwork. Students are taken on an imaginary fossil hunt. Following a script read by the instructor, students "find" (remove from envelope) paper "fossils" of some unknown creature, only a few at a time. Each time, they attempt to reconstruct the creature, and each time their interpretation tends to change as new pieces are "found."

Again, this activity was explicitly targeted toward Diversity of Scientific Thinking ("This is not an experimental science. What processes and skills are necessary to do this work?", "Is this a good example of 'the' scientific method?"), Science & Certainty ("Did your inferences change with addition of new data?", "Will you ever be 100% certain?"), Cooperation & Collaboration ("Were you more or less effective working as a group in this activity?", "If you could form an expert group to analyze this data, what specific backgrounds would you look for?"), and Analysis & Interpretation of Data ("What background knowledge did you and your group bring to the activity that allowed you to come to the hypothesis you did?", "How does a scientist's background influence their interpretation of data?"). The activity and discussion lasted about an hour and a half.

The four activities described above were conducted over a four session unit on teaching NOS in the secondary science classroom. Taken together, they provided explicit and reflective NOS instruction on the aspects of Diversity of Scientific Thinking, Science & Certainty, Cooperation & Collaboration, and Analysis & Interpretation of Data. As shown in Table 3, they were also reinforced by targeted readings and further discussions.

Participants

Seventeen secondary preservice science teachers participated in this study. We report here findings based upon analysis of data for 14 (10 white females and 4 white males) for whom complete data sets were obtained. All participants had an undergraduate degree in science areas, one of them held a master's degree in entomology, and another had long-term experience as a chemist in industry. Five participants were selected for summative interviews for more detailed data on the range of NOS conceptions, reactions to the course intervention, and patterns of development to represent the rest.

Data Collection and Analysis

The main data collection method was written responses to an open-ended assessment instrument (Appendix). A total of 12 questions were written to assess 12 aspects of NOS. Through a pilot test in the previous year, wording of questions were refined to improve the quality of the responses received. Among the 12 aspects assessed, 10 were from Osborne et al.'s Delphi study (2003). Two additional assessment items, Use of Models and Role of Theory, were added to reflect recent discussion in the literature (Justi & Driel, 2005; Smith & Wenk, 2006). Not all items on the assessment instrument were explicitly taught during the course. The aspects not taught include Hypothesis & Prediction, Creativity, Questioning, and Use of Models. These items were used as controls for the instrument. As would be expected, preservice teachers' conceptions of all of these aspects were almost the same throughout the entire study in contrast to the targeted aspects explicitly addressed in the course. These controlled aspects, therefore, demonstrated the usefulness of the assessment instrument and coding process for assessing the learning of preservice teachers.

In both the written and verbal instructions, participants were asked to respond to each of the items and to provide examples to better illustrate their conceptions. The instrument was administered twice, once as a pre-assessment before the course and again as a post-assessment at the conclusion of the course. It took about 45 minutes for the participants to answer the questions for each administration.

At the end of the study, summative interviews were conducted with five participants. The summative interview data were used as further data on the role of the course activities and readings in student learning. Participants were selected for summative interviews based on their availability.

Both administrations of the instrument were analyzed to create profiles of each participant. Participants' responses were coded for each of the 12 aspects of NOS assessed. Although each assessment item focused on a certain aspect of NOS, we examined responses across items because the different aspects of NOS were relevant to some degree and were responded as such by some participants. Individual aspects of NOS were coded as *consistent, partially consistent,* or *inconsistent* with reform documents. For example, for the Role of Theory aspect, a response of "scientific theories are both explanatory and predictive in nature and can be modified with the addition of new evidence" was coded as consistent. The response "scientific theories are explanations of nature" was coded as partially consistent and "scientific theories are guesses made by scientists" as inconsistent.

In order to examine changes in conceptions over the course, coding results from the pre- and post-assessments were compared. Then, across all participants, a comparison was made of the overall changes between the pre- and the post-assessment. The percentage of change was calculated for each aspect of NOS across participants to represent the percentage of participants (those who were not already at the consistent level) whose post-assessment responses increased by one or more categories over the course of the intervention (% Change column in the Table 3).

Results and Discussion

The purpose of this study was to examine the relative efficacy of explicit and reflective instruction using targeted activities and readings on preservice secondary science teachers' conceptions of NOS. In general, the data reveals an overall pattern concerning the relative degree of change of NOS conceptions over the course intervention and the number of explicit and reflective activities and readings. More specifically, those aspects explicitly taught using a combination of activities and readings showed the greatest change whereas those aspects taught using readings alone were only moderately affected.

Most Developed

The preservice teachers in this study developed their ideas about both the Diversity in Scientific Thinking and Science & Certainty aspects much more than the other aspects of NOS (86% and 73% change respectively). The instructional strategy for both aspects included all four activities and between four and five targeted readings taught using an explicit and reflective approach. It was likely that through targeted readings and activities, the preservice teachers had more opportunities to reflect on certain aspects of NOS resulting in greater learning. In other words, those aspects were emphasized more than others.

For the Diversity in Scientific Thinking aspect, all participants initially held naïve conceptions by stating a belief in a universal scientific method. However, those participants changed their ideas by one or two levels in the post-assessment to explicit statements denying a universal scientific method. Instead, responses discussed guidelines and criteria for what makes something scientific.

Among those participants not already at a consistent level concerning Science & Certainty, 73% also changed their conceptions after the course intervention. Initially they expressed a belief in the certainty of scientific knowledge, but in the post-assessment, most acknowledged uncertainty in science in one way or another. When compared to the pre-assessment, the changes in conceptions of this aspect were three-fold. First, in accommodating the notion of uncertainty, the majority of participants explicitly mentioned the durability of scientific knowledge. Second, participants shifted their explanation of any uncertainty in science from a matter of amount of data on a topic to a matter of evidence regarding the topic. The third pattern of change in the conception of uncertainty of science was a shift in the examples used to justify their responses. Many initially used scientific facts to support their claims of science being certain; later, they used scientific theories to describe science and certainty.

Together, these two aspects of NOS showed a high degree of development over the course intervention. They were also the only two aspects to include in the instructional strategy both activities and readings taught using an explicit and reflective approach.

Moderately Developed

In contrast to the aspects of NOS above, 57% and 55% of participants, respectively, whose initial conceptions were not consistent with the reform documents, developed their conceptions of Cooperation & Collaboration and Analysis & Interpretation of Data over the course. The aspect of Cooperation & Collaboration initially revealed a higher degree of understanding than the other aspects assessed. Half of the participants held a conception that was consistent with our definition, claiming that science is a collaborative enterprise in which, although individuals may make significant contributions, scientific work is often carried out in groups and scientific knowledge claims are generally shared and must survive a process of critical peer review. Of the remaining half that did not hold consistent views initially, 57% held more sophisticated views after the course. In response to the aspect of Analysis & Interpretation of Data, six participants' conceptions of the reasons for differing interpretations of data shifted from personal differences and biases to the theoretical and content backgrounds of the researchers. In other words, they shifted toward a more theoretically grounded view of science.

The instructional strategy for these two aspects was similar to that of the most developed aspects. An explicit and reflective approach was utilized with all four activities. Where the strategy differs, however, is in the number of targeted readings. These two aspects had two to three targeted readings in contrast to the four to five readings targeted to the previous aspects.

Least Developed

The final two aspects of NOS were the least developed of the targeted aspects of NOS over the course. Only 50% of participants' conceptions of both the Historical Development of Scientific Thinking and the Role of Theory were affected by the course intervention. In terms of the Historical Development of Scientific Knowledge, those who did improve their conceptions had initially expressed either an evolutionary or a revolutionary view of the Historical Development of Scientific Knowledge. After the course intervention this developed as they combined the two conceptions into a more sophisticated view. Participants who initially had difficulty in responding to the Role of Theory item, more often expressed both the explanatory and predictive nature of scientific theories on the post-assessment.

The instructional strategy for these two aspects of NOS differed from the others in that no activities were explicitly targeted towards them. Both aspects, however, did have four targeted readings which were utilized in an explicit and reflective approach.

Links to Curriculum

In addition to the NOS assessment instruments, we also examined the coursework and post-instructional interviews (conducted 8 months after the course was completed) for explicit links between course activities and readings and changes in NOS understandings. Of the four activities explicitly targeted to aspects of NOS, only two were explicitly mentioned indicating an impact on their understanding. The Tricky Tracks activity was mentioned by one of the participants in the interview in relation to their response to the Diversity in Scientific Thinking assessment question. According to this student, the activity revealed that some scientists "don't use the scientific method we learned about in school." Instead, as the participant expressed in her post-assessment, there are "a lot of different ways to do science."

The Cube activity was mentioned by two of the five participants examined. One participant mentioned in her post-instructional interview that she learned "a lot about the differences between inferences and observation," a link to the Analysis & Interpretation of Data aspect, and that she used the activity in her student teaching. To her, the activity was "a good way of bringing across the point [about] how you do science." It helped her learn about Science & Certainty because she was initially "100% sure of what was on the bottom," until hearing other interpretations from the class.

The second participant to explicitly mention the Cube activity first directly referenced it on his post-assessment response to the Analysis & Interpretation of Data question which changed from an inconsistent to a partially consistent response: "Each group inferences different ideas from the same data. Just like the cube activity." When asked in the post-instructional interview about relevant activities, the same participant once again referenced the Cube activity. However, after referencing the Cube activity by name, he also references, although more indirectly, the Dino Facts and Great Fossil Find activities: "we did a series of activities where you couldn't see the end product and had to figure it out." He states that these activities helped develop his understandings of the Diversity of Scientific Thinking and Science & Certainty. Thus, this participant saw a direct link to these two aspects, and yet referenced the Cube activity explicitly to explain his response to the Analysis & Interpretation of Data question.

In addition to the activities, one participant specifically mentioned the reading "Words Scientists Don't Use" (Ben-Ari, 2005a) in relation to the Science & Certainty aspect of NOS. Examining the difficulties associated with using words such as 'prove' and 'theory' in the classroom, the participant explained in his interview that he believes "in order to get a good grasp of science you really have to know that some things in science are really well known whereas other things are just being tried out."

The common mention of class activities after a long period of time indicated that those activities had an impact on the preservice teachers' understanding. The participants cited those activities not just as mere memory of past learning experience but as evidence of their newly refined conceptions. Moreover, the data indicated potential use of those activities in actual classroom teaching. This suggested that explicit teaching of NOS had affected not only preservice teachers' own understanding of NOS but also their willingness to utilize their learning experiences in their classroom teaching.

Conclusions and Implications

Research over the past two decades has pointed to the relative efficacy of an explicit and reflective approach to NOS instruction (Abd-El-Khalick & Akerson, 2004). In addition, Akerson, Morrison, and McDuffie (2006) found that an activity-based course intervention was more effective in developing the knowledge of NOS than reflective discussion. Our study adds to the finding that activities along with targeted reading might be more effective for learning. The current study was designed to determine the relative efficacy of activities and readings when targeted to specific aspects of NOS and instructed in an explicit and reflective manner. Cross-referencing the change in the participants' conceptions of the targeted aspects over the course with the instructional strategy employed reveals a clear pattern of relative efficacy.

The data reveals an instructional approach consisting of a combination of activities and targeted readings to be the most effective. Using this approach, two aspects of NOS (Diversity in Scientific Thinking and Science & Certainty) were highly developed for the participants over the course. A similar combination, differing only by the number of targeted readings, led to a reduced effect for two aspects (Cooperation & Collaboration and Analysis & Interpretation of Data). An instructional approach that consists only of targeted readings, however, led to less development over the course (Historical Development of Scientific Knowledge and Role of Theory). Finally, those aspects included in course discussions and general readings but not targeted for in specific activities or readings were largely unchanged.

Although our findings show relative efficacies of different teaching approaches in preference to a combination of targeted reading and activities, it is plausible that general reading with no specific aspects of NOS targeted had provided a general overview in which readings and activities for specific aspects were embedded and highlighted. Our study is limited in informing how general reading and targeted reading and activities interact each other to produce the learning gained reported in this study. Further research on organization of readings and activities of different characters will further inform teacher educators in designing effective courses on NOS.

References

Abd-El-Khalick, F. (2001). Embedding Nature of Science Instruction in Preservice Elementary Science Courses: Abandoning Scientism, But... *Journal of Science Teacher Education*, *12*(3), 215-233.

Abd-El-Khalick, F., & Akerson, V.L. (2004). Learning as conceptual change: Factors mediating the development of preservice elementary teachers' views of nature of science. *Science Education*, *88*(5), 785-810.

Akerson, V.L., Morrison, J.A., & 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.

American Association for the Advancement of Science [AAAS]. (1990). *Science for all Americans*. New York: Oxford University Press.

American Association for the Advancement of Science [AAAS]. (1993). *Benchmarks for Science Literacy* (p. 418). New York: Oxford University Press.

Bartholomew, H., Osborne, J., & Ratcliffe, M. (2004). Teaching Students" Ideas-About-Science": Five Dimensions of Effective Practice. *Science Education*, *88*(5), 655-682.

Ben-Ari, M. (2005a). Words scientists don't use. In *Just a Theory: Exploring the Nature of Science* (pp. 45-61). Prometheus Books.

Ben-Ari, M. (2005b). Just a theory: What scientists do. In *Just a Theory: Exploring the Nature of Science* (pp. 23-43). Prometheus Books.

Ben-Ari, M. (2005c). Falsificationism: If it might be wrong, it's science. In *Just a Theory: Exploring the Nature of Science* (pp. 63-78). Prometheus Books.

Cobern, W., & Loving, C. (1998). The Card Exchange: Introducing the Philosophy of Science. In W. F. McComas (Ed.), *The Nature of Science in Science Education: Rationales and Strategies* (pp. 73-82). Kluwer Academic Publishers.

Farber, P. (2003). Teaching Evolution & the Nature of Science. *American Biology Teacher*, *65*, 347-354.

Gess-Newsome, J. (1999). Teachers' knowledge and beliefs about subject matter and its impact on instruction. In J. Gess-Newsome & N. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education: The construct and its implications for science education* (pp. 51–94). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Hagen, J. B., Allchin, D., & Singer, F. (1996). Lynn Margulis: The question of how cells evolved. In *Doing biology*. New York, NY: HarperCollins College Publishers.

Justi, R., & van Driel, J. (2006). The use of the Interconnected Model of Teacher Professional Growth for understanding the development of science teachers' knowledge on models and modelling. *Teaching and Teacher Education*, *22*(4), 437-450.

Kang, N.-H., & Wallace, C. S. (2005). Secondary science teachers' use of laboratory activities: Linking epistemological beliefs, goals, and practices. Science Education, 89(1), 140-165.

Khishfe, R., & Abd-El-Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of Research in Science Teaching*, *39*(7), 551-578.

Lederman, N. (1992). Students' and Teachers' Conceptions of the Nature of Science: A Review of the Research. *Journal of Research in Science Teaching*, *29*(4), p331-59.

Lederman, N. (1998). The state of science education: Subject matter without context. *Electronic Journal of Science Education*, *3*(2), 1-12.

Lederman, N. (2007). Nature of science: Past, present, and future. In S. K. Abell & N. Lederman (Eds.), *Handbook of research on science teaching and learning* (pp. 831-879). London: Lawrence Erlbaum Associates.

Lederman, N. G., & Abd-El-Khalick, F. (1998). Avoiding de-natured science: Activities that promote understandings of the nature of science. In W. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (pp. 83-126). Dordrecht, The Netherlands: Kluwer.

Lederman, N. G., & Lederman, J. S. (2004). Revising Instruction to Teach Nature of Science. *Science Teacher*, *71*(9), 4.

Lin, H., & Chen, C. C. (2002). Promoting preservice chemistry teachers' understanding about the nature of science through history. *Journal of Research in Science Teaching*, *39*(9), 773-792.

National Academy of Sciences [NAS]. (1998). *Teaching About Evolution and the Nature of Science*. Washington, D.C.: National Academy Press.

National Research Council [NRC]. (1996). *National Science Education Standards*. Washington, D.C.: National Academic Press.

Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What "ideas-about-science" should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching*, *40*(7), 692-720.

Randak, S., & Kimmel, M. (1998). The great fossil find. *Evolution & the Nature of Science Institutes*. Retrieved June 7, 2008, from http://www.indiana.edu/~ensiweb/lessons/gr.fs.fd.html.

Schwartz, R. (2007). What's in a word?: How word choice can develop (mis)conceptions about the nature of science. *Science Scope*, *31*(2), 42-47.

Schwartz, R. S., Lederman, N. G., & 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*(4), 610-645.

Schwartz, R., & Lederman, N. (2002). "It's the Nature of the Beast": The Influence of Knowledge and Intentions on Learning and Teaching Nature of Science. *Journal of Research in Science Teaching*, *39*(3), 205-236.

Scotchmoor, J. (1997). Dino Facts. *Learning from the fossil record*. Retrieved June 7, 2008, from http://www.ucmp.berkeley.edu/fosrec/ScotchmoorDino.html.

Smith, C. L., & Wenk, L. (2006). Relations among three aspects of first-year college students epistemologies of science. *Journal of Research in Science Teaching*, *43*(8), 747.

Wivagg, D., & Allchin, D. (2002). The Dogma of "The Scientific Method". *American Biology Teacher*, *64*, 645-646.

Table 1

Descriptions of NOS Themes

NOS Theme	Description
Science & Certainty (Assessment item 1)	Much of scientific knowledge is well established and beyond reasonable doubt, while other scientific knowledge is more open to legitimate doubt. Current scientific knowledge is the best we have but may be subject to change in the future given new evidence or new interpretations of old evidence.
Analysis & Interpretation of Data (Assessment item 2)	The practice of science involves skilful analysis and interpretation of data. Scientific knowledge claims do not emerge simply from the data but through a process of interpretation and theory building that can require sophisticated skills. It is possible for scientists legitimately to come to different interpretations of the same data, and therefore to disagree. Interpretations are based on the scientists' current paradigm.
Scientific Method & Critical Testing (Assessment item 3)	Science uses the experimental method to test ideas that include basic techniques and the use of controls in particular. The outcome of a single experiment is rarely sufficient to establish a knowledge claim.
Hypothesis & Prediction (Assessment item 4)	Scientists make a hypothesis either from their observations or their theories. Once confirmed, theories allow predictions.
Creativity in Science (Assessment item 5)	Creativity is a vital, yet personal, ingredient in all aspects of science.
Science & Questioning (Assessment item 6)	An important aspect of the work of a scientist is the continual and cyclical process of asking questions and seeking answers, which then lead to new questions. This process leads to the emergence of new scientific theories and techniques, which are then tested.
Cooperation & Collaboration (Assessment item 7)	Science is a communal activity. Although individuals may make significant contributions, scientific work is often carried out in groups, frequently of a multidisciplinary and international nature. New knowledge claims are generally shared and, to be accepted by the community, must survive a process of critical peer review.
Science and Technology (Assessment item 8)	Although there is a distinction between science and technology, the two are increasingly interdependent as new scientific discoveries are reliant on new technology and new science enables new technology.
Historical Development of Scientific Knowledge	The history of science reveals both evolutionary and revolutionary changes. With new evidence and interpretation, old ideas are replaced or supplemented by newer ones.

(Assessment item 9)	
Diversity in Scientific Thinking (Assessment item 10)	Science uses a range of methods and approaches and there is no one scientific method or approach. Different fields of science require different methods as they ask different types of questions.
Role of Models * (Assessment item 11)	Scientists use models in order to explain, predict, and represent phenomena of their research. Models are not always exact representations of nature. Various models are used including scale models and mental models.
Role of Theory * (Assessment item 12)	A scientific theory is a concise and coherent set of concepts, claims, and laws that can be used to explain and predict natural phenomena. They provide a framework for research and are sometimes modified scientists try to make them coherent with new evidence.

Adapted from Osborne et al. (2003).

*Denotes aspects of NOS not included in Osborne et al. (2003) but included in this study.

Table 2

Course Readings

General NOS readings:

- American Association for the Advancement of Science [AAAS]. (1990). *Science for all Americans*. New York: Oxford University Press.
- National Academy of Sciences. (1998). *Teaching About Evolution and the Nature of Science*. Washington, D.C.: National Academy Press.

Targeted NOS readings

- Farber, P. (2003). Teaching Evolution & the Nature of Science. *American Biology Teacher*, *65*, 347-354.
- Hagen, J. B., Allchin, D., & Singer, F. (1996). Lynn Margulis: The question of how cells evolved. In *Doing biology*. New York, NY: HarperCollins College Publishers.
- Schwartz, R. (2007). What's in a word?: How word choice can develop (mis)conceptions about the nature of science. *Science Scope*, *31*(2), 42-47.
- Wivagg, D., & Allchin, D. (2002). The Dogma of "The Scientific Method". *American Biology Teacher*, *64*, 645-646.
- Ben-Ari, M. (2005a). Words scientists don't use. In *Just a Theory: Exploring the Nature of Science* (pp. 45-61). Prometheus Books.
- Ben-Ari, M. (2005b). Just a theory: What scientists do. In *Just a Theory: Exploring the Nature of Science* (pp. 23-43). Prometheus Books.
- Ben-Ari, M. (2005c). Falsificationism: If it might be wrong, it’s science. In *Just a Theory: Exploring the Nature of Science* (pp. 63-78). Prometheus Books.

Table 3

Changes in Understandings of NOS Aspects Based on Activities and Readings

Aspect of NOS	Activities	Readings	% Change (Pre/Post)*
Diversity in Scientific Thinking	The Great Fossil Find Dino Facts Tricky Tracks Cube activity	• ([NAS], 1998) • (Farber, 2003) • (Hagen, Allchin, & Singer, 1996) • (Wivagg & Allchin, 2002)	**86%**
Science & Certainty	The Great Fossil Find Dino Facts Tricky Tracks Cube activity	• ([NAS], 1998) • (Ben-Ari, 2005a, 2005b, 2005c) • (Farber, 2003) • (Hagen, Allchin, & Singer, 1996) • (Schwartz, 2007)	**73%**
Cooperation & Collaboration	The Great Fossil Find Dino Facts Tricky tracks Cube activity	• ([NAS], 1998) • (Ben-Ari, 2005c) • (Hagen, Allchin, & Singer, 1996)	**57%**
Analysis & Interpretation of Data	The Great Fossil Find Dino Facts Tricky Tracks Cube activity	• ([NAS], 1998) • (Hagen, Allchin, & Singer, 1996)	**55%**
Historical Development of Scientific Knowledge		• ([NAS], 1998) • (Ben-Ari, 2005c) • (Farber, 2003) • (Hagen, Allchin, & Singer, 1996)	**50%**
Role of Theory		• ([NAS], 1998) • (Ben-Ari, 2005a, 2005b) • (Farber, 2003) • (Hagen, Allchin, & Singer, 1996)	**50%**
Science & Technology			**44%**
Scientific Method & Critical Testing			**36%**
Science & Questioning			**36%**
Creativity			**29%**
Role of Models			**29%**
Hypothesis & Prediction			**7%**

*Percentage whose post-assessment response increased by one or more categories after the course and were not already at the consistent level before the course.

Appendix

Assessment Questions*

1. How certain is scientific knowledge? Is there a range of certainty? If so, provide examples.
2. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions?
3. What is an experiment? Does the development of scientific knowledge require experiments? Why or why not?
4. What role do predictions and hypotheses play in developing scientific explanations?
5. Is creativity an important aspect of science? If so, how? Can you provide an example?
6. How does questioning fit into the scientific process?
7. Does new scientific knowledge in science (i.e. relativity, plate tectonics) stem from individuals or the community of scientists as a whole? How?
8. Do technology and science affect each other? If so, how?
9. How has science progressed historically? What happens to the old ideas when new ones come to light?
10. Is there a universal scientific method? If yes, then what is it? If no, then what, if any, rules govern what is "scientific"?
11. What is a model in science? Provide an example. For what purposes do scientists use models?
12. What are scientific theories? What role do they play in the scientific process?

*Selected only those relevant to the current report