# Teaching Nature of Science within a Controversial Topic: Integrated versus Nonintegrated

Rola Khishfe,[1] Norman Lederman[2]

[1]*School of Education, Loyola University Chicago, 820 North Michigan Avenue, Chicago, Illinois 60611*
[2]*Illinois Institute of Technology*

*Received 28 July 2005; Accepted 4 August 2005*

Abstract: This study investigated the influence of two different explicit instructional approaches in promoting more informed understandings of nature of science (NOS) among students. Participants, a total of 42 students, comprised two groups in two intact sections of ninth grade. Participants in the two groups were taught environmental science by their regular classroom teacher, with the difference being the context in which NOS was explicitly taught. For the ''integrated'' group, NOS instruction was related to the science content about global warming. For the ''nonintegrated'' group, NOS was taught through a set of activities that specifically addressed NOS issues and were dispersed across the content about global warming. The treatment for both groups spanned 6 weeks and addressed a unit about global warming and NOS. An open-ended questionnaire, in conjunction with semistructured interviews, was used to assess students' views before and after instruction. Results showed improvements in participants' views of NOS regardless of whether NOS was integrated within the regular content about global warming. Comparison of differences between the two groups showed ''slightly'' greater improvement in the informed views of the integrated group participants. On the other hand, there was greater improvement in the transitional views of the nonintegrated group participants. Therefore, the overall results did not provide any conclusive evidence in favor of one approach over the other. Implications on the teaching and learning of NOS are discussed. © 2006 Wiley Periodicals, Inc. J Res Sci Teach 43: 395–418, 2006

Achieving scientific literacy is a perennial goal of science education. Nature of science (NOS) is an essential component in achieving scientific literacy (American Association for the Advancement of Science [AAAS], 1989, 1993; National Research Council [NRC], 1996). This objective has been emphasized explicitly in all recent reform movements (AAAS, 1989, 1993; NRC, 1996).

---

*Correspondence to*: R. Khishfe; E-mail: rkhishf@luc.edu
DOI 10.1002/tea.20137
Published online 6 March 2006 in Wiley InterScience (www.interscience.wiley.com).

## Nature of Science

There is no agreement among philosophers, historians, and sociologists of science on a specific definition for NOS. However, there is an acceptable level of generality about some aspects or characteristics of the scientific enterprise (Lederman, in press) that are accessible and relevant to K-12 students' everyday lives (Abd-El-Khalick, Bell, & Lederman, 1998), which can be found in recent work by Elby and Hammer (2001) and Rudolph (2003). Moreover, these aspects have been emphasized in recent reform documents in science education, such as *Benchmarks for Science Literacy* and the *National Science Education Standards* (AAAS, 1993; NRC, 1996). These aspects include understanding that scientific knowledge is: tentative (subject to change); empirically based (based on and/or derived from observations of the natural world); subjective (influenced by scientists' background, experiences, and biases); partly the product of human imagination and creativity (involves the invention of explanations); and socially and culturally embedded. Two additional aspects are the distinctions between observations and inferences, and the functions of, and relationships between, scientific theories and laws.

Research has consistently shown that students have naive understandings of NOS, irrespective of the curricula and the research attempts used to enhance students' views of NOS (e.g., Crumb, 1965; Jungwirth, 1970; Meichtry, 1992; Tamir, 1972; Trent, 1965; Welch & Walberg, 1972). Abd-El-Khalick and Lederman (2000) claimed that failure of curricula and other research attempts, which they labeled as implicit, was due to the underlying assumption that students would learn NOS automatically as a result of studying science and engaging in inquiry activities. Instead, they argued that an understanding of NOS should be taken to be a cognitive learning outcome, which needs to be explicitly addressed and should be planned for instead of being anticipated as a side effect or secondary product. They recommended explicit attention to the various aspects of NOS, and an emphasis on students' awareness of NOS aspects through student reflection on the activities in which they are engaged.

Evidence has suggested that an explicit approach is relatively more effective in improving students' and teachers' conceptions of NOS than an implicit approach that utilizes hands-on or inquiry-oriented instruction (Abd-El-Khalick & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002). However, even with an explicit approach, much is still desired; the utilization of an explicit approach has met with limited success in enhancing more informed understandings among students (e.g., Carey, Evans, Honda, Jay, & Unger, 1989; Durkee, 1974).

One possible explanation for the limited success of the research efforts might be related to the context in which NOS has been explicitly taught. Many researchers (e.g., Brickhouse, Dagher, Letts, & Shipman, 2000; Clough, 2003; Ryder, Leach, & Driver, 1999) have suggested that the explicit teaching of NOS as integrated within the context of the science content would lead to more improvements in students' conceptions of NOS. Clough (2003) argued that NOS activities, which directly aim to teach NOS, are insufficient for developing students' conceptions because they are not linked tightly to the science content. To what extent are these claims supported by empirical research?

## Explicit Approaches to Teach NOS

Generally speaking, "context" for NOS can be conceptualized as integrated or nonintegrated with respect to the science content. In an integrated approach, NOS is taught as embedded within the science content. This approach, however, should not be confused with an implicit approach, which assumes that students will automatically understand NOS as a result of studying the science content. On the contrary, NOS is planned for and explicitly addressed in relation to the regular science content. On the other hand, nonintegrated instruction of NOS involves teaching of the tentative and empirical aspects of NOS through a relevant NOS activity (Lederman & Abd-El-Khalick, 1998) or lectures that specifically address these issues (Durkee, 1974) without relating it to the regular science content.

Evidence regarding the effectiveness of integrated explicit approaches is inconclusive. Two studies have utilized elements from the history of science. In the first study, Klopfer and Cooley (1963) assessed the influence of the *History of Science Cases for High Schools* (HOSC) curriculum on students' conceptions of NOS. The treatment lasted about 5 months. The authors reported that the HOSC instruction methods promoted better understandings among high school students. However, the authors did not provide any documentation of the treatment, so their results are in question. Along the same lines, Solomon, Duveen, Scot, and McCarthy (1992) investigated the effect of a course that used elements from history of science on middle school students' understandings of NOS. The students experienced six science units that were presented in a historical context, in addition to practical laboratory investigations. The results showed improvement in students' conceptions of some aspects of NOS. However, the authors attributed these improvements to a Hawthorne effect.

On the other hand, the attempt by Khishfe and Abd-El-Khalick (2002) was more influential in promoting informed understandings of NOS among students. In their study, they investigated the effect of an explicit inquiry-oriented instruction, which lasted for 2.5 months, on sixth grade students' conceptions of NOS. By the end of the study, participants who experienced explicit inquiry-oriented instruction demonstrated more adequate understandings of the emphasized NOS aspects. However, only the views of less than 50% of participants were influenced, which the authors partly attributed to the influence of the context in which NOS instruction was integrated.

In the nonintegrated approaches, NOS was taught as separate from the regular science content through inquiry activities, NOS activities, and/or lectures, which had the specific goal of addressing students' understandings of NOS. In a study by Durkee (1974), participants were studying a 6-week physics astronomy course at a summer science institute. One period per week was devoted to topics concerned specifically with understandings of NOS, but it was not connected to the physics content under study. This model presented NOS instruction in several sessions that were "distributed" across the science content course. Results showed positive, yet statistically insignificant, gains in students' understandings.

In two other studies (Carey et al., 1989; Liu & Lederman, 2002), participants were seventh graders and NOS instruction consisted of intensive inquiry and/or NOS activities followed by explicit discussions and reflections. Both studies showed little improvement in students' views of NOS. In the first study, by Liu and Lederman (2002), students participated in a 5-day summer camp that involved intensive NOS activities (Lederman & Abd-El-Khalick, 1998). The little change in participants' views of NOS was attributed, by the authors, to a ceiling effect. In the second study, by Carey et al. (1989), students participated in a 3-week unit that involved inquiry activities. Results showed a gain in the interview scores from pre- to posttest. However, these reported gains were not practically significant.

As far as communicating informed understandings of NOS to students is concerned, the existing evidence is inconclusive regarding the effectiveness of existing efforts that utilized integrated and nonintegrated approaches on students' learning of NOS. In general, very few studies have focused on an explicit approach to address students' NOS understandings at the K-12 levels. Little is known about the relationship between the context in which NOS is explicitly taught and students' learning of NOS. Bell and Matkins (2003) investigated this relationship at the teacher level. They found that an explicit approach to teach NOS led to improvement in teachers' NOS understandings regardless of whether the explicit NOS instruction was integrated within controversial science content, yet the effect was slightly greater when NOS was contextualized within the controversial science topic. As such, the context in which NOS was explicitly taught did not seem to ‘‘significantly’’ influence the learning of NOS among teachers. The present study aims to explore whether that would be the case with secondary students.

The purpose of this study was to investigate the effectiveness of two explicit instructional approaches in enhancing more informed NOS understandings among students. These ‘‘informed views’’ correspond to current views of NOS as advocated in recent reform documents in science education (e.g., AAAS, 1990, 1993; NRC, 1996). The research question that guided the study was: What is the relative effectiveness of two different explicit instructional approaches (integrated and nonintegrated), when coupled with a controversial science topic, in developing informed conceptions of NOS among ninth graders?

## Method

### *Participants*

Participants were a total of 42 ninth grade students, taught by the same teacher, in two intact classes in an urban public high school in Chicago with a low to middle socioeconomic status. The diversity of the student population at the school was: 17.3% white; 18.6% black; 58.3% Hispanic; 5.3% Asian/Pacific Islander; and 0.5% Native American (Illinois School Report Card, 2003).

The teacher participated for 1 year in a 5-year NSF Teacher Enhancement Project, whose goal was to promote teachers’ and students’ understandings of NOS and their ability to do and understand inquiry. The project involved monthly workshops during the academic year, followed by a 2-week summer institute. The selection of the teacher from 50 teacher participants, who participated in the second year of the project, was purposefully based on three criteria. The first involved evidence of improvement of the teacher’s views of NOS during participation in the project and the ability to transfer informed views into own classroom practices. The selection measure used for this criterion involved teachers’ pre-, and posttest responses to an open-ended questionnaire (Views of Nature of Science) as well as the review of videotaped lessons of the teacher, which showed changes in his/her classroom instruction of NOS. The second criterion was the availability of more than one section of the same grade level taught by the teacher. The third requirement was the teacher’s consent to participate in the study.

The selected teacher was a 29-year-old man who was teaching environmental science. His educational background includes a major in biology and a minor in marine biology. His areas of certification are biology and general science for grades 6–12. At the time of the study, the teacher had been teaching environmental science at the high school level for 4 years. Student participants comprised two groups in two intact sections of ninth grade, who were taught environmental science by the selected teacher.

The two sections were randomly assigned (flip of a coin) to the two treatments: integrated and nonintegrated NOS instruction. The first section had 21 students (14 males, 7 females) and was assigned to the nonintegrated treatment. The average age of participants in this group was 14.8 years. This section is referred to hereafter as the ‘‘nonintegrated group.’’ The second section had 21 students (11 males, 10 females), and was assigned to the integrated treatment. The average age of participants in this group was 14.6 years. This section is referred to hereafter as the ‘‘integrated group.’’ The two groups were similar with respect to ethnic diversity, science achievement, and age.

### *Procedure*

At the beginning of the study, participants in the two groups were administered a five-item open-ended questionnaire, the *Nature of Science Questionnaire* (Appendix). A total of 10 participants were randomly selected for interviews at the beginning of the study (5 from the integrated group, and 5 from the nonintegrated group). The treatment spanned 6 weeks. At the conclusion of the study, all students were administered the same open-ended questionnaire, and a total of another 10 randomly selected participants were interviewed from the two groups.

### *Instruments*

An open-ended questionnaire was used in conjunction with semistructured individual interviews. The use of open-ended items, as opposed to forced-choice types found in standardized tests, allows respondents to explicate their own views and the assumptions that underlie these views (Lederman, Wade, & Bell, 1998). The purpose of the interviews was to ensure the researcher's interpretations correspond to those of participants and thus validate students' responses to the open-ended questionnaire for this particular sample (Lederman & O'Malley, 1990).

*NOS questionnaire.* The first four questionnaire items (Appendix) were taken and slightly modified from the *Nature of Science Survey* used by Khishfe and Abd-El-Khalick (2002). A fifth item (Appendix, item 5) was added to address the subjective aspect of NOS in the context of the present study. To establish their content validity, the items were examined by a panel consisting of three science education university professors, two scientists, and four science teachers. These experts made some suggestions and some of the items were slightly modified. Further, the questionnaire was pilot-tested with 48 students enrolled in two ninth grade sections at a nonparticipant school. Eight of these students were randomly selected and individually interviewed. During the interviews, they were asked to read the questionnaire items and comment on the meanings they derived from them as well as explain their responses to those items. The final version of the questionnaire comprised five items, two of which were generic (Appendix, items 1 and 4) and three were content-embedded (Appendix, items 2, 3, and 5).

*Interviews.* The semistructured interviews were used to further establish the validity of the questionnaire and guarantee that the researchers' interpretations matched those of the participants. Lederman, Abd-El-Khalick, Bell, and Schwartz (2002) found that interviewing 15–20% is sufficient to determine the meaning associated with a certain group of participants in a certain context. A random sample of 25% of the total students from each group was chosen for individual interviews. The only reason for interviewing a representative sample rather than all the students was feasibility, given the timeline of the study.

The interviews were conducted by the first author and lasted 25–50 minutes. During the interviews, students were given their questionnaires and asked to explain and elaborate on their responses. The interviewer avoided direct cues and limited her discourse to encouraging participants to elaborate, provide examples, and clarify their ideas. Follow-up questions were sometimes used to elicit participants' ideas. For instance, when interviewees responded positively to the first item on the NOS questionnaire that scientific knowledge will change, they were asked, "Change can have two levels: change in the sense of adding new knowledge to the existing knowledge, or change of the existing knowledge itself. Which change are you referring to?" For the second item about the atom, students were asked, "Have scientists ever seen an atom?" If they responded positively, they were asked to explain how scientists saw an atom. If, on the other hand, they responded negatively, they were then asked to explain how scientists came up with the structure of the atom. As for the third item, the meaning of imagination and creativity was described as including creating and inventing something from the mind. Students were then asked, "Do you think that scientists use their imagination and creativity in that sense in their investigations and experiments?" With regard to the last item about global warming, students were asked, "Does it surprise you that scientists disagree when they are looking at the same data?" and "If data support both groups, will we ever determine who is right?"

All interviews were audio-taped and transcribed verbatim for analysis. The same procedure and follow-up questions were used during the pre-, and postinterviews.

*The Treatment*

The first author met with the teacher 3 weeks prior to the beginning of the study for about 10 sessions, which resulted in the design and revision of the global warming unit to include NOS instruction as integrated and as nonintegrated within that content. Participants in the two groups were instructed by the same teacher (their regular classroom science teacher), and covered the same science content about global warming. The treatment spanned 6 weeks, during which participants in both the integrated and nonintegrated groups were instructed about NOS and global warming for four 45-minute sessions per week as part of their regular science lessons; the difference between the two groups was the context in which NOS was taught. In this study, the model of nonintegrated NOS instruction was similar to that employed by Durkee (1974), where NOS instruction was separate yet dispersed and intermittent within the global warming content. No connections were made between NOS and the content of global warming for the nonintegrated group.

Five aspects of NOS, which the researcher believes are accessible to high school students, were emphasized in this study. This belief is based on previous findings that the two aspects, the social/cultural and the distinction between theories and laws, were more difficult to teach to pre-service teachers than the other five aspects (e.g., Abd-El-Khalick et al., 1998; Bell, Lederman, & Abd-El-Khalick, 2000). The first NOS aspect emphasized in this study is that scientific knowledge is tentative. Students should understand that the analysis of scientific knowledge is subject to change in light of new evidence. For example, the theories that scientists have about global warming might change if scientists find more evidence or if scientists reinterpret the exiting evidence in a different perspective. The second aspect addressed is that scientific knowledge is empirical. It is based on or derived from observations of the natural world. For example, scientists created their theories on global warming based on observations and data from experiments. Third, scientific knowledge is a product of human imagination and creativity, where scientists use their minds to invent explanations. For example, scientists constructed their theories about global warming by partly using their imagination and creativity, because scientists never have all the data. The fourth aspect emphasized in the study is the distinction between observations and inferences. Observations are descriptions of nature that can be directly accessed by the senses, whereas inferences cannot be directly accessed by the senses. For example, scientists make observations about the change in the climate and then they use these observations to infer about the possible reasons behind the global warming. Fifth, scientific knowledge is subjective, meaning that it is not possible to make objective interpretations and conclusions without being influenced by one's biases, prior knowledge and experience, and social factors. For example, two scientists might come up with two different inferences when making the same observation about global warming.

In the integrated approach, NOS was taught in relation to the regular science content about global warming. Explicit reflective discussions about NOS aspects (e.g., the empirical and the tentative) followed and were related to the science lessons about global warming. In that sense, NOS was embedded within the science content. This approach would help students build bridges and relate between NOS and the science content they were studying.

Likewise, participants in the nonintegrated groups engaged in the same science content about global warming and the same emphasized NOS aspects. However, the teaching of the science content and NOS was separate. NOS was taught by engaging students in several generic (non–content-embedded) NOS activities (Lederman & Abd-El-Khalick, 1998), which were interspersed within the science lessons. Dispersing NOS instruction across the unit allows students to experience multiple exposures to NOS, which would give them more time to assimilate and articulate their NOS understandings. It should not be overemphasized that, although NOS instruction was dispersed across the science content about global warming, it was not intentionally connected to it. Explicit reflective discussions about NOS aspects followed each activity, where it was related to the work of scientists and the development of scientific knowledge. For instance, students in the nonintegrated group engaged in *The Cubes* activity (Lederman & Abd-El-Khalick, 1998) and learned about the empirical, tentative, creative/imaginative aspects of NOS, as well as the distinction between observation and inference. NOS instruction was followed by instruction about global warming. This approach provides more focus for the learning of each of the two contents (regular science content and NOS). The NOS activities provide concrete and familiar experiences that are not complicated by science content (Clough, 2003). Teaching NOS and the science content as separate might distribute the cognitive load (Pollock, Chandler, & Sweller, 2002) on students. In contrast, students in an integrated approach are required to learn both NOS and the science content simultaneously.

The *Global Climate* unit lasted 6 weeks and included four topics, which lasted for several sessions (45 minutes each). The topics included in the *Global Climate* unit (Table 1) were: "Modeling the Greenhouse Effect"; "Ice Cores"; "Global Temperatures and Carbon Dioxide During the Past 160,000 Years"; and "The Debate." For example, one of the topics in the unit focused on ice cores and it lasted for six sessions (a total of 270 minutes). Table 1 outlines the NOS instruction undertaken, the time spent, and the NOS aspects emphasized within each topic for both groups. As noted earlier, participants in both groups engaged in the same content lessons but the context of NOS instruction was different. NOS instruction was included for both groups in each of the four major science topics within the unit.

Further examination of Table 1 shows that more time per lesson was spent on NOS instruction with the nonintegrated group. The total time spent on NOS instruction for the integrated groups was about five sessions. In comparison, the total time spent on NOS instruction for the nonintegrated groups was about eight sessions. To avoid the introduction of engagement time as a conflating factor, students in the integrated group were engaged in relevant and meaningful discussions of the target content to equalize the additional engagement time that participants in the nonintegrated group spent on participating in NOS activities. During these discussions, more applications of the target concepts/content were introduced and elaborated. It is very important to note that the extra time used by the nonintegrated groups on NOS instruction was mostly spent in participation of the activity, but the actual time spent discussing NOS aspects was almost equal between the two groups. As such, this variation in time for NOS instruction should not have affected the results.

In what follows is an illustration of NOS instruction within this topic in the unit about ice cores, which lasted for six sessions, and the objectives were to have students: (a) explain the role of ice cores in providing a detailed record of what was happening in the world over the past several ice ages, and (b) understand and give examples about how ice cores allow scientists to predict the impact of global warming. Students in the two groups were given a handout that documents records about climate change, temperature, and global warming that have been retrieved through the collection of ice cores.

*Integrated NOS instruction.* For the integrated group, NOS discussions were guided by some questions that were presented at the end of the lessons about ice cores. For instance, students were asked, "Are scientists able to measure the temperature of the Earth directly?" Some students

Table 1
*Overview of the* Global Warming *Unit for the Environmental Integrated and Nonintegrated Groups*

| Science Topic | Group | NOS Instruction | Time Spent on NOS Instruction | NOS Aspects Discussed |
|---|---|---|---|---|
| "Modeling the Greenhouse Effect" (8 sessions) | Integrated | • NOS instruction at end of the lesson<br>• Guiding questions, discussions, and reflections of NOS aspects as they relate to modeling the greenhouse effect | 90 minutes (2 sessions) | 1. Tentative; 2. Empirical; 3. Imaginative/creative; 4. Observation vs. inference |
| | Nonintegrated | • NOS instruction prior to the lesson<br>• *Mystery Bag* activity (Schwartz, Lederman, & Smith, 1999) followed by guiding questions, discussions, and reflections of aspects in relation to activity | 135 minutes (3 sessions) | 1. Tentative; 2. Empirical; 3. Imaginative/creative; 4. Subjective; 5. Observation vs. inference |
| "Ice Cores" (6 sessions) | Integrated | • NOS instruction at end of the lesson<br>• Guiding questions, discussions, and reflections of NOS aspects as they relate to ice cores | 45 minutes (1 session) | 1. Tentative; 2. Empirical; 3. Imaginative/creative; 4. Observation vs. inference |
| | Nonintegrated | • NOS instruction prior to the lesson<br>• *The Hole Picture!* activity (Lederman & Abd-El-Khalick, 1998) followed by guiding questions, discussions, and reflections of aspects in relation to activity | 90 minutes (2 sessions) | 1. Tentative; 2. Empirical; 3. Imaginative/creative; 4. Observation vs. inference |

| Science Topic | Group | NOS Instruction | Time Spent on NOS Instruction | NOS Aspects Discussed |
|---|---|---|---|---|
| "Temperatures and Carbon Dioxide During the Past 160,000 Years" (7 sessions) | Integrated | • NOS instruction at end of the lesson<br>• Guiding questions, discussions, and reflections of NOS aspects as they relate to temperature and carbon dioxide | 45 minutes (1 session) | 1. Tentative; 2. Empirical; 3. Imaginative/creative; 4. Observation vs. inference; 5. Subjective |
| | Nonintegrated | • NOS instruction prior to the lesson<br>• The *Cubes* activity (Lederman & Abd-El-Khalick, 1998) followed by guiding questions, discussions, and reflections of aspects in relation to activity | 45 minutes (1 session) | 1. Tentative; 2. Empirical; 3. Imaginative/creative; 4. Subjective; 5. Observation vs. inference |
| "The Debate" (4 sessions) | Integrated | • NOS instruction at end of the lesson<br>• Guiding questions, discussions, and reflections of aspects in relation to two positions on global warming | 45 minutes (1 session) | 1. Tentative; 2. Empirical; 3. Observation vs. inference; 4. Subjective |
| | Nonintegrated | • NOS instruction prior to the lesson<br>• *Real Fossils, Real Science* activity (Lederman & Abd-El-Khalick, 1998) followed by guiding questions, discussions, and reflections of NOS aspects in relation to activity | 90 minutes (2 sessions) | 1. Tentative; 2. Empirical; 3. Imaginative/creative; 4. Subjective; 5. Observation vs. inference |

answered that scientists measure this indirectly by measuring the ratio of the isotopes of water and hydrogen trapped in the ice core sample. At that point, the teacher stressed that scientists take ice core samples from various locations and they use these samples to infer what lies below the surface that was not sampled. The teacher then emphasized that measuring the temperature is based on observations (ice core samples) and inferences (areas without direct samples).

Another guiding question aimed to address the tentative and empirical aspects of NOS, ''Do you think that scientific knowledge about these ratios is absolute or certain?'' This resulted in a discussion that led to the conclusion that scientific knowledge is subject to change (tentative) as more ice cores (evidence) are collected.

To discuss the creative and imaginative aspect of NOS, the teacher asked, ''Can scientists get all samples of ice cores?'' This led to a discussion about samples and their limitations. The teacher then explained how scientists have to fill in the ''missing pieces of the puzzle'' to generate a final picture of what they believe the whole picture would look like. The discussion centered on the imaginative and creative aspects of NOS, where scientists use their imagination and creativity to make sense of the data they have collected and come up with a final picture or an answer.

*Nonintegrated NOS instruction.* For the nonintegrated group, a NOS activity was presented prior to the lessons about ice cores. The NOS activity included with the lesson about ice cores was *The Hole Picture!* For a detailed description of this activity, see Lederman and Abd-El-Khalick (1998). Briefly, each group was given a manila folder (with the holes or inserts inside). They were informed that the inserts have certain colored shapes glued to them. Students, without removing the inserts, were instructed to figure out those shapes and colors. The only available information to the students was what they see of the colored paper through the holes. Students were asked to trace their proposed shapes on a paper and then present their findings to the whole class:

After the NOS activity, the discussion was guided by some questions about the activity in relation to emphasized NOS aspects. For instance, students were asked, ''Did you observe what was in the inserts?'' Some students answered that there were pieces of evidence provided by the holes, and that made them conclude what was inside. The teacher then emphasized that they made observations from the holes and then they used these observations to make inferences of what shapes were in the inserts. Students were also asked, ''Are you absolute or certain of what shapes and colors were in the inserts?'' That resulted in a discussion of how all scientific knowledge is subject to change (tentative aspects of NOS) as more evidence (empirical aspect of NOS) is accumulated, like making more holes in the folder. To address the creative and imaginative aspect of NOS, the teacher explained that, similar to scientists, they were able to only observe through the inserts, so they had to use their imagination and creativity to literally fill in the gaps between the holes to generate a final picture of what they thought the colored pieces of paper look like.

*Engagement time.* The integrated group participants were engaged in discussions and reflections of NOS aspects for one session (45 minutes) at the end of the topic ''Ice Cores.'' The nonintegrated group participants were engaged in the NOS activity, *The Hole Picture!*, for two sessions (90 minutes) prior to presenting the lessons about ice cores. In the first session, participants were engaged in the NOS activity. The second session focused on discussions and reflections of NOS aspects in relation to the activity. To equalize the additional engagement time that participants in the nonintegrated group spent on NOS, participants in the integrated group were asked to bring articles about ice cores (from newspapers, magazines, and/or the internet) and discuss them in small groups.

To minimize the bias of treatment, certain procedures were followed throughout the study. First, the teacher was asked to follow explicit written scripts (lesson plans) detailing the lessons in the *Global Climate* unit, which were the result of shared work between the teacher and the first author. Second, the first author conducted classroom observations of 85% of all the sessions for both the integrated and nonintegrated groups. These observations were distributed across the whole treatment, the aim of which was to document the correspondence between the written scripts and the actual instruction. During the observations, the researcher kept field notes of instruction for both groups with a purposeful focus on documenting the instruction of the target NOS aspects. In addition, observations focused on documenting the lack of connections between NOS instruction and the science content for the nonintegrated groups. The written field notes were then used to check the correspondence of the actual instruction with the written lesson plans. The few unobserved sessions for both groups (about 15%) were video-taped and then reviewed and analyzed by the researcher to generate field notes that document the instruction of NOS aspects, as well as lack of connections between NOS and science content for the nonintegrated group. Similarly, the field notes were used to check the correspondence of the actual instruction with the written lesson plans. Analysis of the field notes, which were generated from the classroom observations and video-taped lessons, showed that the teacher generally followed the lesson plans and written scripts with minimal deviations.

## Data Analysis

As mentioned earlier, only two intact classes were included in this investigation so as to permit the in-depth data collection and analysis of teaching and student learning necessitated by the research question of interest. Because the classes were intact groups, the experimental unit was the class ($n = 2$). A sample size this small does not permit the inferential statistics. In addition, the treatment (instruction in NOS) was clearly presented to each class and not to individual students. Thus, the assumption of independence of observation cannot be maintained, which also negates the use of the students as the unit of analysis. Although it is easy to find research reports that incorrectly use the student as the unit of analysis in such cases, which artificially inflates the sample size, the research and statistics literature is rich in discussions of the inappropriateness of using the student as the unit of analysis in studies sampling intact classes (e.g., Glass & Stanley, 1970; Herron, Luce, & Neie, 1976; Hurlbert, 1984; Lederman & Niess, 2001; Raths, 1967).

To analyze the data, a systematic process consistent with the analysis protocols illustrated by Strauss and Corbin (1990) was used. The first author analyzed the data. The second author selected and independently analyzed a blind random sample (about 25%) from each of the two groups. The analysis procedure was conducted in two stages. First, the interview transcripts and the corresponding questionnaires were analyzed separately. The preinstruction questionnaires of the 10 participants interviewed were used to generate a profile of their views of the target NOS aspects. The two profiles, which were independently generated from the questionnaires and the interviews, were compared for each participant interviewed. Comparison revealed no discrepancies between the two profiles, thus confirming the face validity of the questionnaire. Similarly, comparisons of the profiles generated from the analysis of postinstruction interview transcripts and the corresponding responses to the postinstruction questionnaire showed no discrepancies. Then, each participant questionnaire was analyzed as a separate case to generate a profile of his/her views of the emphasized NOS aspects. This analysis generated pre- and postinstruction profiles for each participant.

The scoring rubric adopted in this study involved the categorization of students' responses (profiles) into naive, informed, or transitional for each NOS aspect. To explain this analytical framework, the reader needs to be aware that each of the five emphasized NOS aspects was targeted in more than one questionnaire item. For example, the tentative aspect was addressed in the first, second, third, and fifth questionnaire items (Appendix), which demonstrated participants' views in more than one context (the change in scientific knowledge, the atom, the dinosaur, and global warming). To categorize a participant's view of the tentative aspect as informed, each individual had to show evidence of an informed view in all the four contexts. A view was categorized as naive if the participant did not exhibit any informed view of the tentative aspect in response to any of the four questionnaire items. If the participant demonstrated informed views in response to some but not all items, then the view was categorized as transitional. It should be noted that some participants demonstrated informed views of the tentative aspect in response to three items, other participants showed informed views in response to two items, and some even exhibited informed views in response to only one item. However, for the purposes of this study, a "conservative" scoring rubric was used and all such views were categorized as transitional. It should be noted that there was about 95% agreement among the two researchers' independent analyses of the selected sample in terms of coding students' answers into the different categories of naive, transitional, and informed.

Finally, participants' profiles, which were categorized into naive, transitional, and informed, were compared between the two groups to assess changes in participants' views for each of the five NOS aspects. Further, the overall improvement represented by the number of participants' who changed their views into informed and transitional for each emphasized NOS aspect from pre- to postinstruction were compared between the two groups to assess the relative effectiveness of the two instructional approaches.

## Results

A coding system was used to distinguish participants in the integrated and nonintegrated groups. A letter and a number identify each participant. The letters "I" and "N" are used to specify participants in the integrated and nonintegrated group, respectively. The numbers run from 1 to 29 in both groups.

For each of the five emphasized NOS aspects, the pre- and postinstruction views of participants in both groups are discussed and then the improvements in participants' views are compared between the two groups. Prior to instruction, the majority of participants in both groups held naive views of the five target aspects of NOS. By the end of the study, participants in both groups showed improvements in their views of the five target aspects.

### *The Tentative Aspect of NOS*

Evidence about participants' views of this aspect was derived from their responses to the first, second, third, and fifth questionnaire items (Appendix). As mentioned earlier, participants' views of the tentative aspect were categorized as naive, informed, or transitional. At the beginning of the study, none of the participants showed informed views of the tentative aspect (i.e., in response to all four items). By the end of the study, participants in both groups showed improvement in their views of this aspect.

*Preinstruction views.* Forty-three percent of participants in the integrated group, compared with more than half of the participants (57%) in the nonintegrated group, demonstrated a naive view of the tentative aspect. Conversely, 57% of participants in the integrated group and 43% in nonintegrated group held transitional views. Of these, some participants exhibited an informed understanding of this aspect in response to two of the four items. For example, participant N-10 understood that scientific knowledge might change with new evidence that might lead to different interpretations:

> Yes [scientific knowledge might change in the future] because scientists keep discovering new things and that might lead to another and might change what they thought was going on with the thing they are observing. (N-10, item 1, pre-questionnaire)

Further, he indicated that he understood that scientists are not certain about the structure of the dinosaur because it is inferred from empirical observations:

> No, [scientists are not certain about how dinosaurs look] because they put skeleton the way they think it was, what if they found two bones from two different dinosaurs and managed to put them together. (N-10, item 3, pre-questionnaire)

However, this participant did not exhibit an informed view of the tentative aspect when discussing the atomic structure and the issue of global warming. In response to the second item, this participant explained that scientists are not certain about structure because they have not ''seen'' the atom. His response indicated that he held the simplistic view that ''seeing is believing''; he did not seem to understand that the structure of the atom is inferred from empirical observations:

> No, they [scientists] are not certain [about atomic structure] unless they were able to see it in front of them. (N-10, item 2, pre-questionnaire)

Similarly, this participant exhibited naive views of the tentative nature of scientific knowledge when discussing the issue of global warming. He seemed to believe that scientists would always get the one ''right'' answer with more research and testing:

> Maybe if they [scientists] keep testing they'll eventually find out who is right because there should be one answer. (N-10, item 5, pre-questionnaire)

*Postinstruction views.* By the end of the study, 42% of participants in the integrated group and 24% in the nonintegrated group (compared with none at the beginning of the study) elucidated informed understandings of the tentative aspect in response to the four items (items 1, 2, 3, and 5). Only one participant (5%) in each group still demonstrated naive views of the tentative aspect. However, the majority of participants in both groups exhibited transitional views (53% in integrated, and 71% in nonintegrated). For example, this participant elucidated informed views in response to three of the four items. He understood that scientific knowledge might change in the future because of new evidence:

> Yes some of scientific knowledge may change. In the future a new discovery might be found and change some of the information they've found. (N-10, item 1, post-questionnaire)

Further, he was able to explain the notion that scientists are not certain about atomic or dinosaur structure because of human imagination and creativity, and different interpretations:

> Scientists are not certain [about atomic structure], they used observations for part of it and their imagination and creativity for the rest, that's why they aren't certain. (N-10, item 2, post-questionnaire)
>
> Scientists are not certain [about how dinosaurs look]. They put a dinosaur skeleton together by their imagination. For example, the T-rex looks all big but it has two little arms

Table 2
*Participants Who Changed Their Views of the Tentative NOS From Pre- to Postinstruction*

| Tentative NOS | Integrated Group | | | Nonintegrated Group | | |
|---|---|---|---|---|---|---|
| | Pre | Post | Δ | Pre | Post | Δ |
| Informed | 0 (0%) | 9 (42%) | 9 (42%) | 0 (0%) | 5 (24%) | 5 (24%) |
| Transitional | 12 (57%) | 11 (53%) | −1 (4%) | 9 (43%) | 15 (71%) | 6 (28%) |
| Naive | 9 (43%) | 1 (5%) | −8 (38%) | 12 (57%) | 1 (5%) | −11 (52%) |

> that they can't do anything with, does that look right? What if it's two dinosaurs that they have put together? (N-10, item 3, post-questionnaire)

However, this participant showed an absolutist view when discussing global warming:

> Yes [it is possible to determine which group is right] if they have enough facts about something they can eventually put them all together and find out who is right. (EN-10, item 5, post-questionnaire)

*Comparison of improvement in views between the two groups.* The number of participants who improved their views of the tentative aspect from pre- to postinstruction was compared between the two groups. Table 2 shows that the difference between the two groups related to the change into informed views was in the order of four students favoring the integrated group, while the difference between the two groups related to the change into transitional views was in the order of seven students favoring the nonintegrated group.

### *The Empirical Aspect of NOS*

Evidence about participants' views of this aspect was obtained from their responses to the first, second, and third questionnaire items (Appendix). At the beginning of the study, none of the participants showed informed views of the tentative aspect (i.e., in response to all four items). By the end of the study, at least half of the participants in both groups exhibited informed views of this aspect.

*Preinstruction views.* A majority of participants in both groups (62% in integrated and 81% in nonintegrated) exhibited naive views of the empirical nature in response to the first, second, and third items. None of the participants held informed views of this aspect. Thirty-eight percent of participants in the integrated group (versus 19% of participants in the nonintegrated group) exhibited transitional views of the empirical aspect. Most of these participants expressed an informed view of the aspect in response to only one item. For example, participant N-1 held an informed understanding of the role of evidence in depicting how dinosaurs look:

> I said shape of their eyes because of bone structure because of the holes, so if there are bigger holes then obviously they [dinosaurs] have bigger eyes and the skin color. I'm not sure but I'm thinking maybe environment, maybe if they're in a very sunny place, they're darker. They had to come up with something and there had to be color and they [scientists] probably discussing [color and shape of dinosaurs] by its surroundings [environment] or how it moves. I'm not sure, I'm guessing by its environment I think they're certain maybe of the shape of it, but not about color. (N-1, item 3, pre-interview)

However, this participant did not show an understanding of the role of evidence in response to the first item:

> Facts, theories, and laws will not change because they've already been proven (N-1, item 1, pre-questionnaire)

Moreover, the participant's response to the second item indicated that she did not understand that scientific knowledge about the atoms could have some merit because it is based on or derived from empirical observations:

> I am not sure because it is so small. An atom is also in everything. I don't think that scientists figured or will ever figure out what an atom looks like. (N-1, item 2, pre-questionnaire)

*Postinstruction views.* By the end of the study, 62% and 47% of participants in the integrated and nonintegrated group, respectively, exhibited informed understandings of the empirical nature of scientific knowledge when responding to the first, second, and third items. Only 5% of participants in integrated group (versus 10% in the nonintegrated group) still held naive views of this aspect. One third of the participants in the integrated group and 43% in the nonintegrated group expressed transitional views about this aspect. For example, participant I-16 expressed an informed view in response to two of the three items. She elucidated informed understandings of the role of evidence in response to the first and third item (relating to dinosaurs), but not in response to the second item about the atomic structure:

> Yes [scientific knowledge might change] because the information that we have is tentative. We might get data supporting the information we have or data turning all the information we have upside down. (I-16, item 1, post-questionnaire)
>
> Scientists gather information and then try to put all the information together. They use their creativity to try to figure this out. They don't have a real dinosaur in front of them so they are not certain. They try to fit the available data and put them together. (I-16, item 3, post-questionnaire)
>
> Scientists got powerful microscopes that help them look at such small structure. (I-16, item 2, post-questionnaire)

*Comparison of improvement in views between the two groups.* The number of participants who improved their views of the empirical aspect from pre- to postinstruction was compared between the two groups. Table 3 shows that the difference between the two groups related to the change into informed views was in the order of three students favoring the integrated group, while the difference between the two groups related to the change into transitional views was in the order of six students favoring of the nonintegrated group.

### *Distinction Between Observation and Inference*

Evidence about participants' views of the distinction between observation and inference was drawn from their responses to the second and third items (Appendix). At the beginning of the

Table 3
*Participants Who Changed Their Views of the Empirical NOS From Pre- to Postinstruction*

| Empirical NOS | Integrated Group | | | Nonintegrated Group | | |
|---|---|---|---|---|---|---|
| | Pre | Post | Δ | Pre | Post | Δ |
| Informed | 0 (0%) | 13 (62%) | 13 (62%) | 0 (0%) | 10 (47%) | 10 (47%) |
| Transitional | 8 (38%) | 7 (33%) | −1 (5%) | 4 (19%) | 9 (43%) | 5 (24%) |
| Naive | 13 (62%) | 1 (5%) | −12 (57%) | 17 (81%) | 2 (10%) | −15 (71%) |

study, a small minority of the participants in both groups showed informed views of this aspect. More than half of the participants in both groups exhibited informed views of this aspect at the conclusion of the study.

*Preinstruction views.* Only one participant in each of the two groups exhibited an informed view of this aspect when responding to the two items about the atom and dinosaur. About half of the participants (48%) in the integrated group (as compared with 71% in the nonintegrated group) revealed a naive view of this aspect in response to the two items. The remaining 47% and 24% of participants in the integrated and nonintegrated groups, respectively, expressed transitional views of the observation/inference distinction. The following example shows the response of participant N-19, which indicates that he understood that the structure of the dinosaur is inferred from empirical observations:

> I don't know about color of skin but for the eyes they would look at the skeleton of the head and look at the eye sockets. Bones can tell you a lot about a person's body. (N-19, item 3, pre-questionnaire)

However, this participant held the view that "seeing is believing" when discussing the atomic structure; he did not seem to understand the distinction between what is observed and what is inferred:

> No [scientists are not certain about structure of atom] since you cannot actually see an atom and how it looks like. (N-19, item 2, pre-questionnaire)

*Postinstruction views.* Seventy-six percent and 57% of participants in the integrated and nonintegrated groups, respectively, demonstrated informed understandings of the distinction between observation and inference in relation to the two items about the atom and dinosaur. These participants indicated an understanding that scientists used their imagination to infer atomic structure and scientists used their imagination to depict how dinosaurs look:

> [Scientists determined atomic structure] by making observations basing themselves on what they saw under microscope. Then they made experiments and then inferences on how structure was supposed to look like by looking at observations and data such as explanations of what was seen such as shape of atom. (I-15, item 2, post-questionnaire)
>
> Fossils have been found and observations have been made about these fossils. The inferences they [scientists] made according to these observations are reasonable and tell that dinosaurs existed before us. Scientists, they look at bones then make inferences of how dinosaurs look according to shape of bones and many other characteristics. These inferences are not proven since we weren't there when dinosaurs existed. The only evidence that scientists use right now to tell how dinosaurs look is fossils. (I-15, item 3, post-questionnaire)

Only a minority of participants in both groups (14% integrated, 10% nonintegrated) did not demonstrate any informed views of this aspect. Only 10% in the integrated group and 33% of participants in the nonintegrated group exhibited transitional views of this aspect.

*Comparison of improvement in views between the two groups.* The number of participants who improved their views of the observation/inference distinction from pre- to postinstruction was compared between the two groups. Table 4 shows that the difference between the two groups related to the change into informed views was in the order of four students in support of the integrated group, while the difference between the two groups related to the change into transitional views was in the order of 10 students favoring the nonintegrated group.

Table 4
*Participants Who Changed Their Views of the Distinction Between Observation and Inference From Pre- to Postinstruction*

| Observation vs. Inference | Integrated Group | | | Nonintegrated Group | | |
|---|---|---|---|---|---|---|
| | Pre | Post | Δ | Pre | Post | Δ |
| Informed | 1 (5%) | 16 (76%) | 15 (71%) | 1 (5%) | 12 (57%) | 11 (52%) |
| Transitional | 10 (47%) | 2 (10%) | − 8 (37%) | 5 (24%) | 7 (33%) | 2 (9%) |
| Naive | 10 (48%) | 3 (14%) | −7 (34%) | 15 (71%) | 2 (10%) | −13 (61%) |

*The Creative/Imaginative Aspect of NOS*

Evidence about participants' views of this aspect was derived from their responses to the second, third, and fourth questionnaire items (Appendix). At the beginning of the study, only a minority of the participants in both groups showed informed views of this aspect. By the end of the study at least about half of the participants in both groups exhibited informed views of the creative aspect.

*Preinstruction views.* Twenty-nine percent and 52% of participants in the integrated and nonintegrated groups, respectively, showed naive understandings of the role of imagination and creativity when discussing the three different items (items 2, 3, and 4) that addressed this aspect. Only a minority of participants (14% integrated, 5% nonintegrated) showed an informed view of this aspect.

More than half of the participants in the integrated group (57%) and 43% in the nonintegrated group expressed transitional views of the creative/imaginative aspect of NOS. For example, participant I-13 exhibited an informed view only in response to the item about the dinosaur (item 3) and the item about scientific investigations/experiments (item 4). This participant showed an understanding of how scientists might use their imagination or creativity in generating the structure of the dinosaurs. Further, she understood that scientists use their imagination and creativity in their investigations, and was also able to connect this to the context of the dinosaur:

> They used the fossils and tried fitting certain things in it like the eye shape and if it fit they figured that's maybe how they looked. The way we think dinosaurs look is because that's the way scientists think they might have looked, scientists guessed. (I-13, item 3, pre-questionnaire)
>
> Yes [scientists use their imagination or creativity] when they interpret things, that's the scientist way of looking at things, for example how dinosaurs looked. A scientist didn't know for sure so he used his imagination and creativity. (I-13, item 4, pre-questionnaire)

Nevertheless, this participant held a naive view when discussing the atom. She did not understand the role of imagination and creativity in the generation of atomic structure:

> I think scientists are certain [of atomic structure] because they have been experimenting with the atom for a long time .... I think they can see the atom by microscope. (I-13, item 3, pre-interview)

*Postinstruction views.* After instruction, 71% and 48% of participants in the integrated and nonintegrated groups, respectively, expressed more informed understandings of the role of imagination and creativity in response to the second, third, and fourth questionnaire items:

Table 5
*Participants Who Changed Their Views of the Creative NOS From Pre- to Postinstruction*

| Creative NOS | Integrated Group | | | Nonintegrated Group | | |
|---|---|---|---|---|---|---|
| | Pre | Post | Δ | Pre | Post | Δ |
| Informed | 3 (14%) | 15 (71%) | 12 (57%) | 1 (5%) | 10 (48%) | 9 (43%) |
| Transitional | 12 (57%) | 4 (19%) | −8 (38%) | 9 (43%) | 11 (52%) | 2 (9%) |
| Naive | 6 (29%) | 2 (10%) | −4 (19%) | 11 (52%) | 0 (0%) | −11 (52%) |

> I believe that scientists are certain but not absolute about the structure of an atom. This is basically where scientists' creativity and imagination come into play. I feel that scientist use them [creativity and imagination] to form some kind of image from the data they extrapolate. (E-3, item 2, post-questionnaire)
>
> Scientists put the pieces of fossils together and make up the creatures that we know as dinosaurs.... Well scientists take the data they observe and use their creativity and imagination to draw out many theories based on the data that supports it. (E-3, item 3, post-questionnaire)
>
> Yes I believe scientists use them when they make models of something that is too big or small to see [solar system, microscopic cells]. Their imaginations are used when they meant to come up with theory of some kind they have to view it in their heads based on the data they know [data that is available to them]. (E-3, item 4, post-questionnaire)

Nineteen percent of participants in the integrated group (versus 52% in the nonintegrated group) demonstrated transitional views of this aspect. Only 10% of participants in the integrated group still held naive views of the creative and imaginative aspect of NOS.

*Comparison of improvement in views between the two groups.* The number of participants who improved their views of the creative aspect from pre- to postinstruction was compared between the two groups. Table 5 shows that the difference between the two groups related to the change into informed views was in the order of three students in support of the integrated group. On the other hand, the difference between the two groups related to the change into transitional views was in the order of 10 students in support of the nonintegrated group.

*The Subjective Aspect of NOS*

Evidence about participants' views of this aspect was derived from their responses to the third and fifth questionnaire items (Appendix). At the beginning of the study, some of the participants in both groups showed informed views of this aspect. By the end of the study, more than half of the participants overall exhibited informed views of this aspect.

*Preinstruction views.* Forty-three percent of participants overall held naive views of the subjective nature of scientific knowledge in response to both items (the issue of dinosaur extinction and global warming). Twenty-eight percent of integrated group participants (compared with 38% of participants in the nonintegrated group) were able to explicate informed understandings of this aspect in response to only one item. For example, the following participant did not understand the subjective aspect when discussing dinosaur extinction. Yet, he understood that scientists might reach different conclusions about global warming when they are looking at same data because of different interpretations:

> [Scientists reach different conclusions about extinction of dinosaurs] not possible, maybe some of them were under the influence of drugs or alcohol. (N-8, item 3, pre-questionnaire)

> [Scientists reach different conclusions about global warming] they might have interpreted the fact in many different ways. (N-8, item 5, pre-questionnaire)

Twenty-nine percent of participants in the integrated group (versus 19% in the nonintegrated group) showed informed understandings of the subjective nature of scientific knowledge in response to the third and fifth items. These participants seemed to understand that scientists might reach different conclusions from the same data ‘‘because they might have studied the data in different ways causing different ideas to emerge’’ (EI-12, item 3, pre-questionnaire).

*Postinstruction views.* At the conclusion of the study, 81% and 62% of participants in integrated and nonintegrated groups, respectively, demonstrated informed understandings of the subjective aspect when they were discussing the issue of dinosaur extinction (item 3) and the issue of global warming (item 5). Only one participant in the integrated group (versus none in nonintegrated) still held naive views of this aspect. Fourteen percent of participants in the integrated group, as compared with 38% in the nonintegrated group, exhibited transitional views. For example, the following participant elucidated informed understandings of the subjective aspect of NOS when discussing global warming. However, she was not able to explicate such informed views when discussing the issue of dinosaur extinction:

> [Scientists reach different conclusions when looking at same data about global warming] because they have their different opinions and their different imagination. (N-16, item 5, post-questionnaire)
>
> [Scientists reach different conclusions when looking at same data about dinosaur extinction] yes, because meteorite and volcanic eruptions has to do with heat and high temp. (N-16, item 3, post-questionnaire)

*Comparison of improvement in views between the two groups.* The number of participants who improved their views of the subjective aspect from pre- to postinstruction was compared between the two groups. Table 6 shows that the difference between the two groups related to the change into informed views was in the order of two students in support of the integrated group. On the other hand, the difference between the two groups related to the change into transitional views was in the order of three students in support of the nonintegrated group.

## Discussion

Developing informed conceptions of NOS among students has been a major goal for science education as portrayed by the major reform movements in science education (AAAS, 1989, 1993; NRC, 1996). The aim of the present study was to inform efforts aimed at achieving this goal by determining whether the improvement of NOS views among students is related to the context in which NOS is taught. This question was investigated by comparing two different explicit instructional approaches in teaching NOS to high school students within the same study under the same conditions of content and teacher influence.

Table 6
*Participants Who Changed Their Views of the Subjective NOS From Pre- to Postinstruction*

| Subjective NOS | Integrated Group | | | Nonintegrated Group | | |
|---|---|---|---|---|---|---|
| | Pre | Post | Δ | Pre | Post | Δ |
| Informed | 6 (29%) | 17 (81%) | 11 (52%) | 4 (19%) | 13 (62%) | 9 (43%) |
| Transitional | 6 (28%) | 3 (14%) | −3 (14%) | 8 (38%) | 8 (38%) | 0 (0%) |
| Naive | 9 (43%) | 1 (5%) | −8 (38%) | 9 (43%) | 0 (0%) | −9 (43%) |

The results showed improvement in students' views of NOS when they were taught NOS with an explicit approach. The context of NOS instruction with respect to the particular science content was of little importance. Relative to students' preinstruction views, the postinstruction views of participants in both the integrated and nonintegrated groups showed improvement in understandings of the five emphasized NOS aspects. For these participants, explicit instruction in NOS appears to have improved their understandings of NOS whether or not instruction was integrated within a science topic. The improvement in students' understandings of NOS into more informed views seemed to be ''slightly'' higher when NOS was integrated within the content. However, comparison between the two groups showed that the difference in improvement (gains in participants' informed views) was in the order of three or four students in support of the integrated approach. Nonetheless, a difference in the order of two to four students is considered to be of minor impact and of little educational value. Thus, it would not be valid to claim that the data support the superiority of one approach over the other.

On the other hand, the improvement in students' naive understandings of NOS into transitional seemed to be greater with the nonintegrated approach. Comparison between the two groups showed that the difference in improvement (gains in participants' transitional views) was in the order of 3–10 students in support of the nonintegrated approach. Again, the overall results do not provide any conclusive evidence to favor one approach over the other.

These results corroborate the findings of previous research (Bell & Matkins, 2003) in which an explicit approach led to improvement in teachers' NOS understandings regardless of whether NOS instruction was integrated within a controversial science issue. The results of this investigation add to this literature because the focus was on the students.

The results of our study can be explained in relation to the following two factors: a ''distributed'' model and controversial topics. The reader should recall that, in each approach (i.e., integrated and nonintegrated), NOS instruction was dispersed across the unit, allowing students to experience multiple exposures to NOS. This distribution of NOS instruction would give students more time to assimilate and articulate their NOS understandings. Leach, Hind, and Ryder (2002) suggested a similar model to introduce NOS issues that they referred to as a ''drip feed,'' which involves short teaching interventions being used throughout the high school science course. They argued that this approach ''allows students to make links between epistemological and conceptual ideas introduced through the science curriculum'' (p. 842). It is important to note that NOS instruction can also be approached using an ''assembled'' model. This model involves teaching NOS independent of content and in a manner that is not distributed across the content. Research comparing the relative effectiveness of ''distributed'' and ''assembled'' models is needed.

It is extremely important to note that the present findings do not suggest that NOS should be taught as separate from the science content. The results merely highlight the relative effectiveness of both approaches in enhancing NOS understandings. It is assumed that NOS understandings learned through a nonintegrated approach could eventually become connected to the science content. Consequently, considering the teaching of NOS and science content as distinct may be an inaccurate conceptualization of what occurs in a classroom. That is, a focus on science content and NOS may be temporally sequenced, but in reality will eventually be connected.

Along these lines, Clough (2003) argued for a mixed model that utilizes both integrated and nonintegrated NOS instruction. He suggested that engaging students in NOS activities, as black-box activities, helps the scaffolding toward contextualized experiences. He further argued for integrated NOS instruction, such as introducing the experimental work of scientists, and then linking instruction to the NOS activities introduced earlier. Thus, the inclusion of both instructional approaches would be recommended for NOS instruction to K-12 students.

A second factor might be that the discussions of NOS aspects are related to discussions of controversial topics (Sadler, Chambers, & Zeidler, 2002). Because science/technology-based issues bring students into direct contact with the values and assumptions, and concepts embodying NOS, such issues might provide an ideal context for promoting students' understandings of NOS (Bell & Matkins, 2003; Bentley & Fleury, 1998; Sadler et al., 2002; Spector, Strong, & La Porta, 1998).

### *Implications*

The present study has implications for the use of integrated and nonintegrated NOS instruction to promote better understandings of NOS among K-12 students in general, but particularly high school students. These implications are related to the teaching practice designed to improve students' views of NOS.

Our study has shown that explicit NOS instruction improves students' views of NOS, regardless of whether it was integrated within the regular science content or taught as separate through generic NOS activities dispersed across the instructional unit. As such, both approaches can be recommended within science instruction. NOS aspects can be interspersed throughout the instructional unit (as integrated or nonintegrated) and offered in an explicit manner so that change in students' views can occur. It follows that extensive curriculum changes are needed to include NOS as a cognitive outcome that can be integrated or nonintegrated within the regular science content.

### *Recommendations for Future Research*

The present study has suggested some possibly fruitful venues for future research. First, the results are limited to the participants and context within which this research was conducted. Participants were not intended to be representative of any larger population. As the main limitation of the study is attributed to the participation of only one teacher within this science discipline, it follows that more research into the relative effectiveness of integrated and nonintegrated instructional approaches to teach NOS need to be pursued with different teachers, within different science disciplines, and at different grade levels, to establish the generalizability of the findings. Second, the relative effectiveness of the two explicit instructional approaches on students' learning of NOS was only related to the instructional unit in the study. The findings might be related to the nature of the topic (i.e., controversial topic or noncontroversial) within which NOS instruction occurred. Bell and Matkins (2003) proposed the coupling of NOS with real-world topics that illustrate the NOS aspects, while enabling application of these aspects. Therefore, research that establishes and elaborates our understanding of this interaction might prove fruitful in enhancing the likelihood of the success of attempts undertaken to enhance students' views of NOS. As such, future research might investigate the relationship between the integration of NOS within controversial versus noncontroversial topics and their influence on students' learning of NOS.

## Appendix

### *Nature of Science Questionnaire*

1. Scientists produce scientific knowledge (facts, theories, laws). Some of this knowledge is found in your science textbooks. Do you think this knowledge (facts, theories, laws) may change in the future? If your answer is ''yes'' or ''no,'' explain why. Give an example.
2. The diagram below shows the atom as having a nucleus in the center with electrons moving around it.

[Diagram showing the structure of the atom]

(a) Do you think scientists are certain about the structure of the atom? Why or why not?
(b) How did scientists determine this atomic structure?

3. The dinosaurs lived millions of years ago.
   (a) How do scientists know that dinosaurs really existed?
   (b) What evidence did scientists use to tell how dinosaurs look like (for example, the color of dinosaur skin, the shape of eyes)?
   (c) Do you think scientists are certain about the way dinosaurs look? Explain what makes them certain or uncertain.
   (d) Scientists agree that about 65 millions of years ago the dinosaurs became extinct. However, scientists disagree about what had caused this to happen. One group of scientists suggest that a huge meteorite hit Earth and caused the extinction. Another group of scientists suggest that violent volcanic eruptions caused the extinction. How is it possible for scientists to reach different conclusions when both groups are using the same data?
4. Scientists try to find answers to their questions by doing investigations/experiments. Do you think that scientists use their imagination and creativity in their investigations/experiments? **YES/NO**
   (a) If **NO**, explain why. Give one example.
   (b) If **YES**, in what part of their investigations (planning, experimenting, making observations, analyzing data, interpretation, making conclusions, etc.) do you think they use their imagination and creativity? Give one example.
5. Scientists disagree about the issue of global warming. Some scientists say that humans are warming the planet by the continuous burning of fossil fuels. Another group of scientists say that the influence of humans is insignificant compared with the natural forces, which have determined the weather for millions of years.
   (a) How is it possible for scientists to arrive at different conclusions when they are looking at the same data?
   (b) Is it possible to determine which group of scientists is right? If yes or no, explain your answer.

## References

Abd-El-Khalick, F., Bell, R.L., & Lederman, N.G. (1998). The nature of science and instructional practice: Making the unnatural natural. Science Education, 82, 417–436.

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

American Association for the Advancement of Science. (1989). Project 2061: Science for all Americans. New York: Oxford University Press.

American Association for the Advancement of Science. (1993). Benchmarks for scientific literacy. New York: Oxford University Press.

Author (2002). Journal of Research in Science Teaching.

Bell, R.L., Lederman, N.G., & Abd-El-Khalick, F. (2000). Developing and acting upon one's conception of the nature of science: A follow-up study. Journal of Research in Science Teaching, 37, 563–581.

Bell, R.L., & Matkins, J.J. (2003). Learning about the nature of science in an elementary science methods course: Content vs. context. Paper presented at the annual meeting of the National Association for Research in Science Teaching (NARST), Philadelphia, PA.

Bentley, M.L., & Fleury, S.C. (1998). Of starting points and destinations: Teacher education and the nature of science. In W.F. McComas (Ed.), The nature of science and science education: Rationales and strategies (pp. 277–291). Dordrecht, The Netherlands: Kluwer.

Brickhouse, N.W., Dagher, Z.R., Letts, W.J., & Shipman, H.L. (2000). Diversity of students' views about evidence, theory, and the interface between science and religion in an astronomy course. Journal of Research in Science Teaching, 37, 340–362.

Carey, S., Evans, R., Honda, M., Jay, E., & 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. International Journal of Science Education, 11, 514–529.

Clough, M.P. (2003, January). Explicit but insufficient: Additional considerations for successful NOS Instruction. Paper presented at the annual meeting of the Association for the Education of Teachers, St. Louis, MO.

Crumb, G.H. (1965). Understanding of science in high school physics. Journal of Research in Science Teaching, 3, 246–250.

Durkee, P. (1974). An analysis of the appropriateness and utilization of TOUS with special reference to high-ability students studying physics. Science Education, 58, 343–356.

Elby, A., & Hammer, D. (2001). On the substance of a sophisticated epistemology. Science Education, 85, 554–567.

Glass, G.V. & Stanley, J.C. (1970). Statistical methods in education and psychology. Englewood Cliffs, NJ: Prentice Hall.

Herron, J.D., Luce, T.G., & Neie, V.E. (1976). The proper experimental unit: Comparative analyses of empirical data. Journal of Research in Science Teaching, 13, 19–27.

Hurlbert, S.H. (1984). Pseudoreplication and the design of ecological field experiments. Ecological Monographs, 54, 187–211.

Jungwirth, E. (1970). An evaluation of the attained development of the intellectual skills needed for understanding of the nature of scientific inquiry by BSCS pupils in Israel. Journal of Research in Science Teaching, 7, 141–151.

Klopfer, L., & Cooley, W. (1963). The history of science cases for high schools in the development of student understanding of science and scientists. Journal of Research in Science Teaching, 1, 33–47.

Leach, J., Hind, A., & Ryder, J. (2003). Designing and evaluating short teaching interventions about the epistemology of science in high school classrooms. Science Education, 87, 831–848.

Lederman, N.G. (in press). Nature of science: Past, present, and future. Handbook of research in science education. Mahwah, NJ: Erlbaum.

Lederman, N.G. (1992). Students' and teachers' conceptions of the nature of science: A review of the Research. Journal of Research in Science Teaching, 29, 331–359.

Lederman, N.G., & 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 and science education: Rationales and strategies (pp. 83–126). Dordrecht, The Netherlands: Kluwer.

Lederman, L., Abd-El-Khalick, F., Bell, R., & Schwartz, R. (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.

Lederman, N.G., & Niess, M. (2001). Not-so-common "common" knowledge. School Science and Mathematics, 101, 1–4.

Lederman, N.G., & O'Malley (1990).

Lederman, N.G., Wade, P.D., & Bell, R.L. (1998). Assessing the nature of science: What is the nature of our assessments? Science and Education, 7, 595–615.

Liu, S., & Lederman, N.G. (2002). Taiwanese gifted students' views of nature of science. School Science and Mathematics, 102, 114–123.

Meichtry, Y.J. (1992). Influencing student understanding of the nature of science: Data from a case of curriculum development. Journal of Research in Science Teaching, 29, 389–407.

National Research Council. (1996). National science education standards. Washington, DC: National Academic Press.

Pollock, E., Chandler, P., & Sweller, J. (2002). Assimilating complex information. Learning and Instruction, 12, 61–86.

Raths, J. (1967). The appropriate experimental unit. Educational Leadership, 25, 263–266.

Rudolph, J.L. (2003). Portraying epistemology: School science in historical context. Science Education, 87, 64–79.

Ryder, J., Leach, J., & Driver, R. (1999). Undergraduate science students' images of science. Journal of Research in Science Teaching, 36, 201–220.

Sadler, T.D., Chambers, W.F., & Zeidler, D. (2002). Investigating the crossroads of socioscientific issues, the nature of science, and critical thinking. Paper presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, LA.

Schwartz, R.S., Lederman, N.G., & Smith, M. (1999). Modeling success during earth science week. Science Scope, 23, 36–37.

Solomon, J., Duveen, J., Scot, L., & McCarthy, S. (1992). Teaching about the nature of science through history: Action research in the classroom. Journal of Research in Science Teaching, 29, 409–421.

Spector, B., Strong, P., & La Porta, T. (1998). Teaching the nature of science as an element of science, technology and society. In W.F. McComas (Ed.), The nature of science and science education: Rationales and strategies (pp. 267–276). Dordrecht, The Netherlands: Kluwer.

Strauss, A., & Corbin, J. (1990). Basics of qualitative research: Grounded theory procedures and techniques. London: Sage.

Tamir, P. (1972). Understanding the process of science by students exposed to different science curricula in Israel. Journal of Research in Science Teaching, 9, 239–245.

Trent, J. (1965). The attainment of the concept "understanding science" using contrasting physics courses. Journal of Research in Science Teaching, 3, 224–229.

Welch, W.W., & Walberg, H.J. (1972). A national experiment in curriculum evaluation. American Educational Research Journal, 9, 373–383.