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Influence of Explicit and Reflective versus Implicit Inquiry-Oriented Instruction on Sixth Graders' Views of Nature of Science

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Abstract: This study investigated the influence of an explicit and reflective inquiry-oriented compared with an implicit inquiry-oriented instructional approach on sixth graders' understandings of nature of science (NOS). The study emphasized the tentative, empirical, inferential, and imaginative and creative NOS. Participants were 62 sixth-grade students in two intact groups. The intervention or explicit group was engaged in inquiry activities followed by reflective discussions of the target NOS aspects. The comparison or implicit group was engaged in the same inquiry activities. However, these latter activities included no explicit references to or discussion of any NOS aspects. Engagement time was balanced for both groups. An open-ended questionnaire in conjunction with semistructured interviews was used to assess participants' NOS views before and at the conclusion of the intervention, which spanned 2.5 months. Before the intervention, the majority of participants in both groups held naive views of the target NOS aspects. The views of the implicit group participants were not different at the conclusion of the study. By comparison, substantially more participants in the explicit group articulated more informed views of one or more of the target NOS aspects. Thus, an explicit and reflective inquiry-oriented approach was more effective than an implicit inquiry-oriented approach in promoting participants' NOS conceptions. These results do not support the intuitively appealing assumption that students would automatically learn about NOS through engagement in science-based inquiry activities. Developing informed conceptions of NOS is a cognitive instructional outcome that requires an explicit and reflective instructional approach. © 2002 Wiley Periodicals, Inc. J Res Sci Teach 39: 551–578, 2002

Helping students develop informed views of nature of science (NOS) is a central goal for science education (American Association for the Advancement of science [AAAS], 1990, 1993; National Research Council [NRC], 1996). However, research has consistently shown that students hold naive views of several important aspects of NOS, including the empirical,

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tentative, inferential, and creative and imaginative nature of scientific knowledge (e.g., Griffiths & Barman, 1995; Horner & Rubba, 1978; Larochelle & Desautels, 1991; Lederman & O'Malley, 1990; Mackay, 1971; Rubba, 1977). For example, a majority of elementary and middle school students believe that scientific knowledge is absolute (BouJaoude, 1996; Rubba, Horner, & Smith, 1981) and that theories could be proven true by the accumulation of empirical evidence (Bady, 1979; Smith, Maclin, Houghton, & Hennessey, 2000). Those students also fail to appreciate the role of scientists' ideas in guiding scientific investigations, which they believe adhere to prescribed stepwise methods that exclude elements of imagination and creativity from the process of generating valid knowledge (BouJaoude, 1996; Meichtry, 1992; Smith et al., 2000).

To mitigate this state of affairs, numerous attempts have been undertaken to enhance learners' views of NOS. These attempts can be categorized under three general approaches: historical, implicit, and explicit and reflective. The following section elucidates the assumptions and presents illustrative examples of each of these approaches. The present study is concerned with comparing the influence of an implicit versus an explicit and reflective instructional approach on sixth graders' NOS views.

General Approaches to Improving Student Conceptions of NOS

The historical approach suggests that incorporating history of science in science teaching can serve to enhance students' NOS views. *History of Science Cases for High Schools* (HOSC) (Klopfer & Watson, 1957) and the *Harvard Project Physics* (HPP) course (Rutherford, Holton, & Watson, 1970) are two notable examples of curricula that adopted the historical approach. A study undertaken by Solomon, Duveen, Scot, and McCarthy (1992) serves to illustrate the historical approach. Solomon et al. aimed to document how learning science through history of science might influence students' views of the tentative nature of scientific ideas and their relationship to the social and cultural contexts within which they were developed. Ninety-four 11- and 14-year-old students experienced six historically oriented science units (Solomon, 1991) in which they explored the development of scientific theories, such as Peter Medawar's theory of immune reactions, and performed simple experiments modeled after the work of scientists, such as Needham, Pasteur, and Puchect.

Although participants' images of scientists and views regarding why scientists subscribe to different theories remained virtually unchanged, Solomon et al. (1992) noted some favorable changes in their participants' views at the conclusion of the study. More students now believed that the purpose of experiments was to generate explanations rather than make discoveries, that scientists know what to expect when they perform an experiment, and that theories are not synonymous with facts. However, given the design of their study, the authors noted that the documented improvements could also be attributed to a Hawthorne effect associated with the participant teachers' enthusiasm and extra classroom help with which they provided students. Moreover, the authors expressed discomfort regarding participants' views on historical settings. Students did not show empathy for past ideas and dismissed past theories as a sort of wrong knowledge. Many students found it difficult to role-play a certain scientist especially when they knew that the scientist was wrong. Students were unable to appreciate the social conditions and contemporary thinking that led scientists to develop certain ideas and make certain decisions.

Evidence concerning the effectiveness of the historical approach is at best inconclusive. In particular, conflicting results were yielded by two large-scale national studies conducted by Klopfer and Cooley (1963) and Welch and Walberg (1972) to assess the influence of the HOSC and HPP course on students' NOS understandings, respectively. Whereas Klopfer and Cooley (see also Solomon et al., 1992) reported favorable changes in learners' views, Welch and Walberg (see also Yager & Wick, 1966) reported that historically oriented science instruction failed to influence students' conceptions of NOS favorably.

The implicit approach contends that by doing science, students will come to understand NOS (Lawson, 1982; Rowe, 1974) and advocates the use of hands-on inquiry-oriented activities and/or science process skills instruction—lacking explicit references to NOS—to enhance students' conceptions of NOS. Most of the 1960s and 1970s curricula, such as the *Physical Science Study Curriculum* (PSSC) and the *Biological Sciences Curriculum Study* (BSCS), adopted such an approach. However, research has consistently shown that the implicit approach was not effective in helping students develop informed NOS views. Indeed, Crumb (1965) and Trent (1965) reported that the inquiry-oriented PSSC curriculum was not more effective than a traditional textbook-centered curriculum in enhancing students' NOS views. Crumb's sample was composed of 1275 students from 29 rural and urban high schools, whereas Trent's sample consisted of 26 experimental and 26 control high schools. In both studies, no significant differences were found between experimental and comparison groups' NOS views as measured by the *Test on Understanding Science* (TOUS) (Klopfer & Cooley, 1961) even after Trent controlled for participants' prior science knowledge and mental ability.

Similarly, Jungwirth (1970) found that 693 10th graders from 25 schools taught using the BSCS Yellow Version did not achieve significantly better scores on the TOUS and *Processes of Science Test* (BSCS, 1962) than comparison students (215 students from seven schools) enrolled in more traditional high school biology programs. Tamir (1972) compared the influence of the BSCS Yellow Version, PSSC physics, and traditional science courses on learners' NOS views. His sample was composed of 3500 students in Grades 9–12 randomly selected from 44 schools. No significant differences were found between participants' NOS views in the different courses as measured by the *Science Processes Inventory* (Welch & Pella, 1967–1968). More recently, Meichtry (1992) investigated the effect of the BSCS program on middle school students' understandings of the developmental, testable, creative, and unified NOS. The experimental group and comparison group was composed of 1004 and 603 Grade 6–8 students in two middle schools that used the BSCS course and a more traditional biology course, respectively. Scores on the *Modified Nature of Scientific Knowledge Scale* (MNSKS) (Meichtry, 1992) showed that the experimental group participants' understandings of the developmental and testable NOS decreased significantly relative to the comparison group students. Meichtry concluded that there is a need for "explicit representation of all aspects of the nature of science by the curriculum content taught and the instructional methodology used by teachers" (p. 405).

Despite such substantial disconfirming evidence, the implicit approach still finds adherents who believe that engagement in inquiry activities would automatically improve students' NOS understandings (e.g., Jelinek, 1998; McComas, 1993; Moss, Abrams, & Kull, 1998). The study undertaken by Moss et al. (1998) serves to illustrate the sort of interventions carried out under the implicit approach. Moss et al. investigated the influence of a yearlong environmental science class on 11th and 12th graders' conceptions of NOS. Throughout the course, students were engaged in inquiry-oriented projects that involved them in doing science in partnership with scientists. Individual interviews conducted with a group of participants throughout the school year revealed no significant changes in their NOS views. Moss et al. reached a conclusion that was repeatedly confirmed in the aforementioned studies of the 1960s and 1970s curricula. They noted, "by merely involving students in science-related projects, they will not necessarily develop an improved understanding of the nature of science" (p. 24).

The ineffectiveness of the implicit approach in enhancing students' NOS views could be attributed to an underlying assumption: namely, that students would automatically develop better

NOS conceptions as a by-product of engagement in science-based inquiry activities or science process skills instruction. Abd-El-Khalick and Lederman (2000)) noted that this assumption is based on the view held by some science educators, which depicts learning about NOS to be an affective learning outcome (e.g., Barufaldi, Bethel, & Lamb, 1977). Alternatively, an understanding of NOS should be considered a cognitive learning outcome and should be taught explicitly rather than expected ''to be assimilated via a kind of osmotic process during the regular science activities'' (Durkee, 1974, p. 352).

The explicit and reflective approach advances that the goal of improving students' NOS views ''should be planned for instead of being anticipated as a side effect or secondary product'' of varying approaches to science teaching (Akindehin, 1988, p. 73). In the context of improving science teachers' NOS views, some advocates of the explicit approach used instruction specifically geared toward various NOS aspects (e.g., Billeh & Hasan, 1975), whereas others augmented such instruction with elements from history and philosophy of science (e.g., Ogunniyi, 1983). More recently, reflective elements have been given prominence within the explicit approach. Abd-El-Khalick (2001), Abd-El-Khalick, Bell, and Lederman (1998), and Akerson, Abd-El-Khalick, and Lederman (2000), used explicit and reflective activity-based instruction (Lederman & Abd-El-Khalick, 1998) to promote teachers' NOS views. In these latter studies, teachers were first explicitly introduced to certain NOS aspects and then provided multiple structured opportunities to reflect on these aspects in the context of the science-based activities in which they were engaged or science content they were learning to help them articulate their views of the target NOS aspects and develop coherent overarching NOS frameworks.

Few explicit and reflective attempts have been undertaken to improve younger students' NOS views. Carey, Evans, Honda, Jay, and Unger (1989) investigated changes in 76 seventh graders' views of the nature of scientific knowledge and inquiry after exposure to a 3-week NOS instructional unit (see also Durkee, 1974). The study featured inquiry activities coupled with structured reflective opportunities. For example, after an activity in which students organized various kinds of animal disguises into different categories, a teacher-led discussion focused on classification systems as explanatory human constructs. Students were also engaged in a black box activity in which they formulated hypotheses and assessed their validity based on evidence, and were then guided to realize similarities between such activities and the work of scientists. Twenty-seven students were randomly interviewed before and at the conclusion of the unit. Carey et al. reported modest gains in students' NOS views. After instruction, more students understood that specific ideas and questions guide inquiry, and that experiments aim to test rather than discover ideas.

Evidence suggests that an explicit and reflective approach could substantially improve learners' NOS views. This evidence, however, derives from interventions undertaken with science teachers (e.g., Abd-El-Khalick et al., 1998; Akerson et al., 2000; Shapiro, 1996). Thus, there is a need to investigate further the influence of an explicit and reflective approach on younger students' NOS views. Moreover, an examination of the literature indicates that an explicit approach is relatively more effective than an implicit one in furthering science teachers' understandings of the scientific enterprise (see Abd-El-Khalick & Lederman, 2000). However, no studies have systematically compared the relative influences of these approaches on either teachers or kindergarten through Grade 12 students' NOS views. Such is the focus of the present study.

Before proceeding with this report, it is crucial to make some important qualifications regarding the conceptualization of an explicit and reflective approach. First, it cannot be overemphasized that this approach should not be confused with didactic teaching. An explicit and reflective approach does not entail drilling students to reiterate certain generalizations about the nature of scientific knowledge. Second, the term *explicit* in the label "explicit and reflective" should not lead the reader to construe the approach in the narrow and technical sense of explicit teaching, which relates to prescribed generic instructional strategies that are "most applicable in those areas where the objective is to master a body of knowledge or learn a skill which can be taught in a step-by-step manner" (Rosenshine & Stevens, 1986, p. 377). Strategies included under the rubric "explicit teaching," such as beginning a lesson with a statement of goals and presenting new materials in small steps followed by student practice, would not go far in helping students internalize and apply the sort of abstract understandings related to the assumptions underlying the development of scientific knowledge and the characteristics of such knowledge. Third, an explicit and reflective approach does not solely invoke elements from history and philosophy of science or exclude science-based inquiry activities. On the contrary, inquiry activities are integral to this approach (Abd-El-Khalick, 2001; Shapiro, 1996).

The term "explicit" in the label "explicit and reflective" 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. The fact that these latter understandings are often translated into specific instructional objectives in teachers' lesson plans does not automatically entail that they will be didactically taught. Constructivist teaching approaches could be used to teach about NOS in the same manner that these approaches are used to help students construct their own conceptions of abstract scientific ideas. On the other hand, the term "reflective" in the label "explicit and reflective" is associated with instructional elements. The term refers to providing students with opportunities to analyze the activities in which they are engaged from various perspectives (e.g., a NOS framework), to map connections between their activities and ones undertaken by others (e.g., scientists), and to draw generalizations about a domain of knowledge (e.g., epistemology of science). The NOS enterprise is a reflective endeavor and the above reflective elements are designed to emulate the sort of activities that historians, philosophers, and sociologists engage in their efforts to understand the workings of science (Abd-El-Khalick & Lederman, 2000, p. 691). Simply put, an explicit and reflective approach emphasizes student awareness of certain NOS aspects in relation to the science-based activities in which they are engaged, and student reflection on these activities from within a framework comprising these NOS aspects.

NOS

Given the multifaceted, complex, and dynamic nature of the scientific endeavor, it should not be surprising that philosophers, historians, and sociologists of science disagree on a specific definition for NOS and many particular issues associated with the generation of valid scientific claims. However, within a certain period of time and at a certain level of generality, there is a shared wisdom (even though no complete agreement) about NOS. For instance, currently it would be difficult to dismiss the theory-laden nature of observation or to defend a deterministic or empiricist conception of NOS. Moreover, at such a level of generality, some important aspects of NOS are virtually noncontroversial. Such NOS aspects have been advanced in recent reform documents in science education, such as *Benchmarks for Science Literacy* (AAAS, 1993, especially Chapter 1) and the *National Science Education Standards* (NRC, 1996, especially Chapter 6).

In the present study, four of these NOS aspects, which we believe are accessible to sixth graders, were adopted and emphasized. These aspects include the tentative, empirical, and creative and imaginative nature of scientific knowledge, as well as the crucial distinction between observation and inference. Table 1 indicates that these four NOS aspects have been emphasized in both the *Benchmarks* (AAAS, 1993) and *Standards* (NRC, 1996) as part of the NOS understandings that students in Grades 6–8 and 5–8 are desired to acquire, respectively. Obviously, the relevant NOS ideas could be presented at varying levels of depth and complexity depending on students' background and grade level. These NOS *Benchmarks* and *Standards* nevertheless provide a relatively clear idea about the sort of NOS understandings expected of sixth graders.

Table 1
Correspondence between NOS aspects emphasized in this study and those emphasized in science education reform documents for sixth graders

Present Study	*Benchmarks for Science Literacy* (AAAS, 1993)	*National Science Education Standards* (NRC, 1996)
Scientific knowledge is tentative (subject to change).	"Scientific knowledge is subject to modification as new information challenges prevailing theories and as a new theory leads to looking at old observations in a new way." (1A:6–8, #2, p. 7)	"Scientists do and have changed their ideas about nature when they encounter new experimental evidence that does not match their existing explanations." (Content standard G: 5–8, nature of science, #1, p. 171)
Scientific knowledge is empirical (based on and/or derived from observations of the natural world).	"Scientists do not pay much attention to claims about how something they know about works unless the claims are backed up with evidence that can be confirmed with logical arguments." (1B: 3–5, #4, p. 11)	"Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models . . . for most major ideas in science, there is experimental and observational confirmation." (Content standard G: 5–8, nature of science, #1, p. 171)
Scientific knowledge is partly the product of human imagination and creativity (involves the invention of theories, explanations, models, etc.).	"Scientific investigations usually involve the collection of relevant evidence, the use of logical reasoning, and the application of imagination in devising hypotheses and explanations to make sense of the collected evidence." (1B: 6–8, #1, p. 12)	"Science is very much a human endeavor, and the work of science relies on basic human qualities, such as reasoning, insight, energy, skill, and creativity" (Content standard G: 5–8, science as a human endeavor, #2, p. 170)
Distinction between observation and inference: Observations are accessible to senses or extensions of the senses whereas inferences are not. Inferences should be logical and consistent with observations on which they are based.	"Scientists' explanations about what happens in the world come partly from what they observe and partly from what they think." (1B: 3–5, #3, p. 11) (Also see above: 1B: 6–8, #1, p. 12.)	(See above: Content standard G: 5–8, science as a human endeavor, #2, p. 170)

In this regard, individuals often conflate NOS with science processes. In agreement with the reform documents (AAAS, 1990, 1993; NRC, 1996), we consider scientific processes to be activities related to the collection and interpretation of data, and the derivation of conclusions. NOS, by comparison, is concerned with the values and epistemologic assumptions underlying these activities (Abd-El-Khalick et al., 1998). For example, observing and hypothesizing are scientific processes. Related NOS conceptions include the understandings that observations are constrained by our perceptual apparatus, that the generation of hypotheses is necessarily imaginative and creative, and that both activities are inherently theory-laden. Although there is overlap and interaction between science processes and NOS, it is nevertheless important to distinguish the two.

Purpose

This study investigated the influence of an explicit and reflective inquiry-oriented approach compared with an implicit inquiry-oriented approach on sixth-grade students' conceptions of the four aforementioned aspects of NOS. Two questions guided the investigation: (a) Does an explicit and reflective inquiry-oriented approach help sixth graders develop informed conceptions of the target NOS aspects? (b) Is an explicit and reflective inquiry-oriented approach more effective than an implicit inquiry-oriented approach in enhancing sixth graders' NOS understandings? This latter question was investigated with the hope of shedding light on the validity of the assumption underlying the implicit approach: namely, that students would necessarily develop adequate conceptions of NOS as a by-product of science process-skills instruction or mere engagement in inquiry activities.

Method

The present study was interpretive in nature (LeCompte & Preissle, 1993) and focused on the meanings that participants ascribed to the emphasized aspects of NOS.

Participants

Participants were 62 sixth graders enrolled in two intact sections in a private school in Beirut, Lebanon, where English is the language of instruction. Participants' average age in both sections was 11 years. Students in one section (33 students, 16 female and 17 male) served as the intervention group, which will be referred to hereafter as the explicit group. Students in the second section (29 students, 12 female and 17 male) served as the comparison group, which will be referred to hereafter as the implicit group. The school science achievements of participants in the two sections were not significantly different ($p > .05$).

Research has shown that learners' NOS understandings are for the larger part independent of science content knowledge, science achievement, and academic achievement, as well as other cognitive, social-personal, and personal variables including logical thinking ability, quantitative aptitude, verbal aptitude, locus of control orientation, and gender (Billeh & Hasan, 1975; Carey & Stauss, 1968, 1970; Olstad, 1969; Scharmann, 1988a, 1988b; Wood, 1972). As such, it was safe to assume that an intact-group pre–post comparison of participants' NOS understandings would allow deriving valid inferences regarding the relative effectiveness of the two investigated approaches in enhancing participants' understandings of the target NOS aspects.

Procedure

A six-item open-ended questionnaire (see Appendix) in conjunction with individual interviews was used to assess participants' views of the target NOS aspects. At the beginning of the study, all 62 participants were administered the questionnaire. Next, a purposeful sample of 16 students, 8 from each the explicit and implicit groups, was chosen for individual interviews. The interviews aimed to validate the NOS questionnaire and generate profiles of participants' views. The intervention, which spanned 2.5 months, followed. At the conclusion of the intervention, the same questionnaire was administered to all participants coupled with individual interviews with 16 students, 8 from each group. These latter participants were different from those chosen for preinstruction interviews. In both administrations, participants completed the NOS questionnaire in class under teacher supervision and took an average of 45 minutes to respond to the questionnaire items.

Instruments

The use of an open-ended questionnaire in conjunction with individual interviews to assess participants' NOS views was undertaken with the intent of avoiding the problems inherent to the use of standardized forced choice paper and pencil NOS assessment instruments, such as the TOUS (Klopfer & Cooley, 1961) and MNSKS (Meichtry, 1992). These instruments are based on the problematic assumption that the meanings respondents ascribe to the instrument items and their reasons for choosing certain responses correspond to those of the instrument developers. Moreover, being of the forced choice type, standardized instruments often end up imposing certain views of NOS on respondents. In contrast, open-ended items allow respondents to elucidate their own views regarding the target aspects of NOS and the reasons that underlie their views (Lederman, Wade, & Bell, 1998).

NOS Questionnaire. Themes for the questionnaire used in the present study were adopted from a questionnaire used by Abd-El-Khalick (1998). Four items were initially drafted (items that were slightly different from Items 1, 2, 3, and 6 in the Appendix) to assess participants' views of the tentative, empirical, and imaginative and creative NOS, as well as the distinction between observation and inference. Two science education professors and two sixth-grade English teachers reviewed the items for content validity and readability, respectively. Next, the questionnaire was pilot-tested with 32 students enrolled in a third nonparticipant sixth-grade section in the participant school. Six of these students were randomly selected and individually interviewed. They were asked to comment on the meanings they derived from reading the questionnaire items and explain their responses to those items.

Pilot students' responses and interviewees' input were used to modify the questionnaire items further. For example, it was evident that respondents ascribed various meanings to the terms *imagination* and *creativity* in the context of responding to one item (Appendix, Item 6). To ensure valid interpretations of participants' responses to this latter item, two additional items (Appendix, Items 4 and 5) were added. These two items asked participants to explicate the meanings of the terms "imagination" and "creativity" and illustrate these meanings with examples. Another modification was related to the Dinosaurs item (Appendix, Item 3). Initially, the item asked, "What evidence did scientists use to tell how dinosaurs look like?" Responses from the pilot administration indicated that students were equating the term "look like" only with the general "shape" of dinosaurs (e.g., being huge, having long necks). This was not the sole intent of the item, which aimed to assess respondents' views of the inferential and creative

NOS (e.g., in relation to depicting the color and texture of dinosaurs' skin) in addition to their views of the empirical NOS (i.e., depictions of dinosaurs are eventually based on and/or consistent with the unearthed fossils). As such, the qualifier, "for example, the shape of dinosaurs bodies, the texture and color of dinosaurs' skin," was added to the item. The final version of the questionnaire was composed of 6 items, 4 of which were generic (Appendix, Items 1, 4, 5, and 6) and 2 content-embedded (Appendix, Items 2 and 3). Of these latter 2, 1 item was related to the atomic nature of matter and the other to dinosaurs.

The inclusion of Item 2 on atomic structure (see Appendix) in the questionnaire requires further justification. Under the new Lebanese science curriculum (Lebanese National Center for Educational Research and Development, 1997), sixth graders are expected to develop a basic understanding of the particulate nature of matter without delving into details, including atomic structure. However, the new curriculum was implemented in phases. During the first year, the curriculum was implemented in 1st, 4th, 7th, and 10th grades. The following year, implementation was extended to the 2nd, 5th, 8th, and 11th grades. At the time of the study, sixth graders were still following the old Lebanese curriculum, which required a basic understanding of atomic models including the Bohr model. Thus, participants' views of atomic structure were explored and the image of atomic structure included in Item 2 was reproduced from their science textbook.

Semistructured Interviews. Given the present study's concern with the meanings that participants ascribed to the emphasized NOS aspects, it was imperative to avoid misinterpreting participants' responses to the questionnaire. Thus, semistructured individual interviews were used to establish the validity of the questionnaire by ensuring that the researchers' interpretations corresponded to those of participants. During the interviews, which were conducted by the first author, students were provided their questionnaires and asked to explain their answers. Interviewees were asked to clarify their responses and support them with additional examples where appropriate. Follow-up questions were used to probe students' ideas in-depth and explore relationships between these ideas. The interviewer observed extended wait time, avoided directive cues, and limited her discourse to encouraging participants to elaborate and clarify their ideas. All interviews, which typically lasted for about 30 minutes, were audiotaped and transcribed verbatim for analysis.

A purposeful sample of 16 students, 8 from each group, was selected for interviews after administration of the questionnaire. A total of 32 participants (52%) were interviewed. After an initial reading of all participants' responses to the questionnaire, purposeful samples were chosen to represent a variety of responses in terms of clarity, length, and completeness. Students in these purposive samples were also balanced in terms of science achievement and gender. Because interviewing all participants was not feasible given the timeline of the study, the purposive samples were chosen to maximize variance and thus allow exploration of a wide range of student responses for the purpose of learning how to read participants' responses to the questionnaire items.

Different students were interviewed at the beginning and conclusion of the study to avoid introduction of the preinstruction interview, which could have served as a treatment, as a confounding variable that could influence participants' responses during postinstruction interviews. This approach allowed the use of postinstruction interview data both to establish the validity of the questionnaire and to facilitate the interpretation of changes in participants' views. However, the reader is reminded that participants' responses to the questionnaire served as the main source of data in the present study. The questionnaire was administered to all participants before and at the conclusion of the study. Changes in participants' views, if any, were mainly gauged from analyses of questionnaire data.

The Intervention

The first author delivered the intervention for the implicit and explicit groups. She was the regular classroom science teacher for the two participating sixth-grade sections. The intervention placed more emphasis on inquiry teaching than is usually undertaken in that particular school. Thus, to ensure the fidelity of the intervention, instructional activities and all pre-and postactivity discussion questions and topics for the implicit and explicit groups were outlined and the first author made every effort to follow the outlines. Furthermore, all intervention sessions were videotaped for both groups. A fixed video camera was placed in the classrooms 1 week before the intervention to habituate students to its presence. At the conclusion of each activity, the two researchers and a third science educator reviewed the videotapes to check for correspondence between classroom activities and the planned intervention for both groups. Continuous monitoring and feedback to the first author ensured close alignment between the planned and the implemented intervention.

Participants were instructed for two 50-minute sessions per week over the course of 10 weeks during which both groups were engaged in the same set of six inquiry activities, each of which spanned two to three sessions. The inquiry activities targeted regular sixth-grade science content. The onset of the intervention corresponded with the beginnings of a physical science unit in which participants explored, over the course of 8 weeks, the structure and properties of matter and energy transformations. The intervention was concluded 2 weeks after the start of an earth science unit in which participants explored the structure of the earth. An overview of the content covered during the intervention is presented in Table 2, which also outlines the inquiry activities undertaken, the general questions that guided those activities, and a brief description of each activity. Below, one of the implemented activities is used to illustrate the nature of the intervention undertaken with the two groups.

A guided inquiry model (Eggen & Kauchak, 1996), which put participants in authentic problem-solving situations and investigations, was adopted in the intervention. This model emphasizes answering questions by reference to evidence collected through student-designed investigations. Students worked in pairs or groups of three throughout the intervention, during which group membership was changed only once. An activity started with the first author posing a problem (Table 2, Column 4: Activities 1 and 6), or a general guiding question (Table 2, Column 4: Activities 2–5). For example, after a brief introduction coupled with illustrative examples of combustion, students were asked, "Does the amount of available air affect the burning of a candle?" Students were then guided to clarify the problem and formulate specific questions that lent themselves to investigation. To continue with the combustion example, after a whole-class teacher-led discussion during which participants were asked to identify the factors involved (e.g., candles, burning, amount of air) and think of ways to clarify and rephrase the original question, participants came up with more specific questions, such as "How long will it take for the candle to stop burning when different amounts of air are supplied?" and "Does the use of different size jars that are placed over a burning candle affect how long the candle will burn?" Student groups did not pursue the same question in most of the activities (Table 2, Column 5). In this case, a few groups decided to investigate whether the amount of available air affected the brightness of the burning candle. Next, participant groups made predictions and designed data collection procedures to answer their questions. For example, the majority of groups decided to invert different-size jars over same-size candles and measure the time it took each candle to go off. Participant groups then presented and defended their data collection procedures to the entire class. Student feedback often entailed modifying the suggested procedures. For instance, students investigating the brightness question had to answer some critical comments relating to "How will you decide how bright is bright?"

Table 2
Topics explored and inquiry activities undertaken over the course of the intervention for both implicit and explicit groups

Topic	Focus of Activity	Activity No.	General Problem/ Question Investigated	Brief Description of Student Activities
Physical science				
Structure of matter	Atomic structure	1	What is the shape of an object you cannot see?	The teacher shot Ping-Pong balls through a wire grid into a large box. Based on observing and recording the behavior of the balls (e.g., passed or did not pass through the box), student groups inferred the shape of an object fixed inside the box. (Abd-El-Khalick, 2002
Properties of matter	Mixtures	2	Does temperature affect the dissolution of salt in water?	Most groups added salt incrementally to equal amounts of water at different temperatures to decide whether temperature affected the amount of salt that could be dissolved. Some groups added the same amount of salt to water at different temperatures to assess whether temperature affected the speed of dissolution.
	Phase changes	3	Does salt affect the melting of ice?	Invariably, student groups compared the melting of same-size ice cubes to which some salt was added with ones with no salt. Some groups also investigated whether the amount of salt used made a difference by adding different amounts of salt to the same-size ice cubes.

Table 2
(*Continued*)

Topic	Focus of Activity	Activity No.	General Problem/ Question Investigated	Brief Description of Student Activities
Energy transformations	Heat and heat transfer	4	Which is a better insulator, Styrofoam or tin?	Student groups compared which of the two containers better retained the heat of the same amount of hot water as indicated by a smaller difference between initial and final temperatures over a fixed period of time.
	Combustion	5	Does the amount of available air affect the burning of a candle?	Groups inverted different-size jars over same-size candles to assess whether the amount of available air affected how long the candles burned. A few groups focused on the effect of available air on the brightness of the burning candles.
Earth science				
Sedimentary rock	Fossils	6	What did the organism from which your fossil fragment came look like?	Each student pair was provided with a fossil fragment and asked to draw the complete organism from which their fragment came. Student pairs then presented their inferred organisms to the class along with descriptions of their organisms' habitats. (Lederman & Abd-El-Khalick, 1998)

After data collection, each group decided how to organize and analyze the data to provide evidence-based answers to their questions. Data from the different groups were pooled in master tables and group findings were shared. Students were then engaged in a whole-class discussion in which they derived some generalizations relating to the original guiding question that targeted specific science content, such as ‘‘burning or combustion cannot happen if air is not available.’’ Students' engagement in the undertaken activities aimed to help them develop understandings of the target science content, and acquire and practice science process skills, such as observing, predicting, measuring, interpreting, and controlling variables. Indeed, in addition to focusing on content, postactivity discussions aimed to make students aware of the science process skills they engaged and contemplate ways to improve their performance of these skills. To this end, students participated in small-group and whole-class discussions centered on science process skills. They grappled with questions such as, "At which point did you decide that your candle stopped burning? Why did you use the same-size candles and different size-jars in this investigation? How did you make sure that your timing across the different tests was consistent? Is there a better way that this group could have used to present their results? What other conclusions could be derived from this set of data? If you were to conduct this investigation again, what would you change and why?"

Up to this point, both the implicit and explicit group participants experienced the same kind of activities and were engaged, to the extent possible, in the same discussions. Beyond this point, however, the intervention implemented with the explicit group differed in one major way: A reflective NOS component followed discussions of content and science process skills. At the end of each activity, all or some of the target NOS aspects were highlighted and the explicit group participants were guided to discuss and reflect on these aspects in relation to the activity at hand.

Discussions after Activity 1 (Table 2) illustrate the crucial differences between the post-activity discussions undertaken with the implicit and explicit group students. With both groups, the postactivity discussion first focused on content—that is, mapping the connections between the activity and Rutherford's work in relation to his major conclusion that the greatest part of the mass of an atom was concentrated in a minute fraction of its volume. This conclusion ultimately fed into a basic introduction to Bohr's atomic model. Second, the discussion focused on science process skills, such as (a) observing, in relation to having multiple observers check the accuracy of the observations; and (b) communication, in relation to devising a way (e.g., a two-coordinate system) to communicate the grid location through which a certain Ping-Pong ball was shot and developing a coding system to record the behavior of the balls quickly and accurately (e.g., a checkmark if a ball went through and an "X" if it did not).

Next, only with the explicit group, the discussion focused on relevant NOS aspects. The aforementioned theme of "knowing is not seeing" was highlighted along with a discussion of the meaning of the term *inference*. For instance, explicit group participants were asked, "Can we say that this is the shape of the object inside the box [pointing to a sketch provided by one group] in the same way we say there are 33 students in this class?" Ensuing discussion focused on inference as a way of learning about things around us that is distinct from observing, though related to it. Participants were asked, "Why did we decide that the sketches provided by some groups needed modification?" and engaged in a discussion about the role of evidence in making inferences or claims about phenomena. Several plausible sketches of the object inside the box were then posted on the chalkboard and participants were asked to comment on why different groups came up with different sketches even though they made the same observations. Students brought up ideas, such as "We think differently," "Not all of us are good in drawing," and "I wanted to draw something that is flat but the others [group members] thought it should be rounded." Ensuing discussions focused on the jumps that scientists such as Rutherford have to make to reach conclusions like the jumps students made in going from checkmarks and X's to sketching the object they believed was inside the box. The creative and imaginative elements of scientists' work were discussed. Also, students were asked what would happen if the grid holes were made smaller and instead of shooting 25 Ping-Pong balls through the box, a BB gun was used to make 250 shots. Many students noted that their drawings would "be better because we will know more, we will have much more observations." Ensuing discussions focused on the empirical and tentative NOS.

It should be noted that this was the first in the set of six inquiry activities, so it involved many guiding questions on the part of the teacher. In general, postdiscussions in the first three activities were guided. The teacher engaged students by constantly prompting and cueing their responses. At first, students were not participating because, as mentioned earlier, they were not used to inquiry instruction. As they engaged more in the different activities, they became more involved. Toward the end of the treatment, they started discussing one or two of the NOS aspects themselves without being prompted by the teacher.

In the last three activities, postdiscussions were less guided. For instance, explicit group participants were asked, "Did you see that air was involved in the burning of the candles? If not, how could you know that air was involved then?" Student responses ranged from a total conflation of their observations (evidence) and inferences (claims consistent with the evidence), such as, "We know because we saw that the candle stopped burning," to articulating some sense of this crucial distinction, such as "No one can see the air, it is invisible anyway, but nothing else is in the jar, so our group guessed that air was part of it [the burning process]." Such answers were capitalized on and differences among observations, guesses, and inferences were highlighted. Explicit group participants were also encouraged to make connections between the different inquiry activities in terms of certain NOS aspects through explicit prompts. For instance, they were asked, "So, we did not see the air but could tell that it was involved in burning. Could we know something without seeing it?" Some participants made insightful connections to Activity 1 (Table 2). They noted, "We could not see inside the carton. But I knew that something was inside the carton and made diagrams of what we think was inside. If there was nothing inside, all the Ping-Pongs would just fly through." Such explicit questions and prompts, which were less guided in the last three activities, helped participants explicate their thinking about and make connections between the undertaken activities and the nature of scientific knowledge.

In whole-class discussions in Activity 6 (Table 2), students started asking each other questions such as, "What was your evidence that your fossil came from this organism?" "How can you support your conclusion?" and "Do you think scientists would get the same organism?" and comments such as, "I thought that scientists can never be wrong," "It's all about the evidence," "So scientists then can make mistakes just like we do!" and "So in science, we may not see everything with our own eyes."

The teacher still highlighted the discussed NOS aspects in the last three activities. However, that involved less guidance and more student participation and involvement. With each activity, students' views seemed to develop, as evidenced from the kind of questions that they were asking both the teacher and each other. The following conversation took place between students in one group after Activity 6 (Table 2). It demonstrated the connections that students were making between the activities undertaken and the nature of scientific knowledge (in particular the empirical, imaginative, and tentative):

Student (S)1: How can they know shape of dinosaurs if people did not see them?

S2: They do not see them. No people were there to see them.

S1: They don't see them so they imagine.

S2: Yah—

S1: And then everybody would imagine anything they want.

S2: Yes, you are right [short pause], but look, their imaginations have to fit what they have.

S1: What do you mean?

> S2: Look at this fragment [pointing at the fossil fragment on his table]. Scientists bring this, look at it first then they try to imagine. And if they find more of this [pointing to fragment] in the same place, then they imagine differently. And if you still don't get it, then go and ask the teacher. Here she is.

Every effort was undertaken to ensure that the duration of the intervention activities was the same for participants in the implicit and explicit groups. The activities for both groups were identical in every respect save for the reflective NOS component in the case of the explicit group. This meant spending more time per activity for students in the explicit group. To avoid the introduction of engagement time as a conflating factor, students in the implicit group were engaged in meaningful discussions of the target content or relevant science process skills to equalize the additional engagement time that participants in the explicit group spent discussing NOS.

Data Analysis

The first author analyzed the data. The second author conducted a blind round of analysis. The few differences that emerged (with $<5\%$ of the responses) were resolved by consensus based on further consultation of the data. This procedure was undertaken to ensure the validity of the analysis given that, as noted earlier, the first author had delivered the intervention, and consequently she might have viewed the data as partially evaluative. However, having taught and interviewed the participants, she offered a unique perspective in terms of interpreting their responses.

Initially, the first author analyzed the preinstruction questionnaires of the 16 interviewed participants to generate a profile of their views of the target NOS aspects. The second author conducted a similar analysis using these participants' interview transcripts. The independently generated profiles were compared and indicated that interpretations of participants' NOS views as elucidated in the questionnaire were congruent to those expressed by participants during individual interviews. Such congruency enhanced confidence in the validity of the questionnaire. The few differences between the two authors' interpretations were negotiated by reference to the interviews, which helped clarify the meanings of some terms and phrases depicted in the questionnaires, such as "certain" and "dreamed the way a dinosaur looked like." This procedure was repeated with the postinstruction questionnaires and interview transcripts of the other 16 interviewees resulting in even better congruency between the two authors' analyses.

Next, both authors independently analyzed all of the participants' NOS questionnaires in the implicit and explicit groups. Each questionnaire was used to generate a summary of a participant's views of the four target NOS aspects. These summaries were used to generate pre- and postinstruction profiles of the target NOS aspects for both groups. The profiles were systematically compared and contrasted between and across groups to answer the questions of interest. There was 95% agreement between the authors' independent analyses.

The analysis did not assume a restrictive one-to-one correspondence between an item on the questionnaire and a target NOS aspect. To be sure, certain items targeted one of the four emphasized NOS aspects to a larger extent than others. For instance, Items 1 and 4 (see Appendix) largely targeted respondents' views of the tentative and creative NOS, respectively. However, views of the target NOS aspects could be explicated in response to other items on the questionnaire. For instance, understandings of the tentative and creative aspects of NOS could be expressed in response to Items 2 and 3 as well. This approach to the analysis had two major advantages. First, it did not construe NOS understandings in the narrow sense of specific desired responses to cues set by specific questions. Rather, participants could demonstrate their NOS understandings in several contexts. Second, this approach allowed researchers to check for meaningful understanding of a NOS aspect versus superficial reiteration of key terms by checking for consistency (or lack thereof) in students' responses across the questionnaire items. For example, in response to Item 1, students might indicate that they believe scientific knowledge could change in the future, without providing examples. This might as well mean that these students endorse a tentative view of NOS. However, if the same students explicitly note in response to Items 2 and 3 that scientists were certain or sure about atomic structure and how dinosaurs looked like, one could hardly say that they have internalized an understanding of the tentativeness of scientific knowledge. By the same token, if students demonstrated understandings of the creative and imaginative NOS in their responses to, say, Items 3 and 6, it would be safe to infer that they developed desired understandings of this NOS aspects. To be sure, if respondents explicated informed views of a target NOS aspect in any one item and there were no inconsistencies or other disconfirming evidence in their questionnaires regarding this aspect, they were judged to have informed views. It follows from the above that in a few cases some participants' responses could not be categorized as pertaining to informed or naive views of the target NOS aspects.

Finally, it is important to note that low inference was used throughout the analysis. This is not to say that participants' responses were taken literally. However, the authors were careful not to load participants' words and phrases with high-inference meanings unless interview data suggested otherwise. For example, many participants often used the terms *prove* and *proof*, which could mean that they harbored an absolutist view of scientific knowledge. However, further probing during the interviews indicated that those participants used the term "proof" to refer to evidence and not to the more robust meaning of the word "proof," which indicates knowing with certainty.

Results

Before instruction, views of the target NOS aspects of participants in the implicit and explicit groups were not different in any substantial way. In addition, the implicit group participants' postinstruction views were not different from their preinstruction views. However, the postinstruction NOS views of participants in the explicit group were substantially different from the views they elucidated at the beginning of the study. Table 3 presents a summary of these results.

The following sections present profiles of participants' pre- and postinstruction views. Ideas related to the four target NOS aspects are necessarily related. However, to make the discussion manageable, participants' views of each target NOS aspect are presented separately. As such, some assignments of quotes to NOS aspects might seem arbitrary: Some participants' quotes that are presented as evidence of naive (or informed) views of one NOS aspect might equally serve as evidence of naive (or informed) views of another target aspect. Nonetheless, this should not be taken to mean that participants' views of the four NOS aspects were always consistent or part of a well-thought and articulated overarching framework. Indeed, participants' views were sometimes inconsistent across the explored aspects. For example, some participants explicated informed views of the empirical and tentative, but not of the creative and imaginative NOS.

In the following sections, each participant is identified by a letter and a number. The letters "I" and "E" are used to identify participants in the implicit and explicit group, respectively. The

Table 3
Percentages of pre- and postinstruction informed and naive views of target NOS aspects for explicit and implicit group participants

	Tentative NOS		Observation vs. Inference		Empirical NOS		Creative and Imaginative NOS	
Group	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Explicit group ($n = 33$)								
Informed	6	52	9	40	6	48	3	34
Naive	85	45	85	60	85	46	82	63
Not categorized	9	3	6	0	9	6	15	3
Implicit group (n = 29)								
Informed	7	7	7	18	4	7	7	4
Naive	86	93	86	78	83	89	83	89
Not categorized	7	0	7	4	13	4	10	7

numbers, which run from 1 to 29 in the implicit group and from 1 to 33 in the explicit group, identify individual participants.

Participants' Preinstruction Views of NOS

Implicit and explicit group participants' preinstruction NOS views were not substantially different. About 85% of participants elucidated naive views of the tentative, empirical, imaginative and creative, and inferential nature of scientific knowledge (Table 3, Rows 4 and 8). Only a small minority of implicit and explicit group participants (about 7%) elucidated informed views of these NOS aspects (Table 3, Rows 3 and 7).

The Tentative Nature of Scientific Knowledge

Eighty-five percent of all participants elucidated naive views of the tentative NOS. They seemed to believe that scientific knowledge is certain or true and does not change. Two major trends were evident in participants' responses in this regard. First, in their responses to the first item on the questionnaire, which asked whether scientific knowledge presented in science textbooks might change in the future, 78% of all participants indicated that scientific knowledge "will never change [because] ... everything scientists say in books is correct" (I3, prequestionnaire). These participants believed that scientists would not admit a claim as part of scientific knowledge or encode it in science textbooks unless they were certain about it. As one participant put it, "No [scientific knowledge would not change], because if the scientists are not sure about it they don't put it in the books for students to learn it" (E22, prequestionnaire). In their responses to the second and third questionnaire items (see Appendix), these participants explicitly noted that scientists were "100% certain" or "sure" about atomic structure and the way dinosaurs are depicted in science textbooks. Second, 20% of participants also noted that scientific knowledge might change in the sense of adding new facts to extant knowledge. This addition, nonetheless, did not entail abandoning or rejecting earlier scientific claims. As one participant put it, "They [scientists] can only add on knowledge but they can't take anything of it because they 100% sure of it" (E23, prequestionnaire).

The reader is reminded that participants' views of a certain NOS aspect were assessed based on their responses to more than one questionnaire item. Thus, there is always some overlap between the percentages provided for major trends in participants' responses. For example, the above two percentages (78% and 20%) seem to add up to more than 85% because eight participants (13%) provided responses that fit into the two major trends. However, altogether 53 participants (85%) explicated naive views of the tentative NOS.

Only a minority of participants (7%) expressed more adequate views of the tentative NOS. For instance, these participants noted that scientists are not certain about the way dinosaurs look like because scientists use their imagination to arrive at the pictures of dinosaurs:

> Scientists found traces that exist millions of years ago. I think that this thing is imagined and the scientist doesn't know how they look . . . they don't know 100%. (E19, prequestionnaire)
>
> Scientists are 50% sure of how dinosaurs look since they do not know their shapes altogether. They only saw its skeleton, they did not see its body . . . only bones without meat and skin. (I17, preinterview)

None of the participants, however, explicitly expressed the view that scientific knowledge is amenable to change in the sense of abandoning certain scientific claims about some natural phenomenon and adopting others.

Distinction Between Observation and Inference. A total of 85% of participants did not demonstrate adequate understandings of the distinction between observation and inference. For these participants, knowing is seeing. Students seemed to believe that to learn about something in nature, scientists simply need to see it. Forty-five percent of participants believed that scientists were certain about the atomic nature of matter because they were able to see atoms using microscopes. As one participant noted, "I cannot see it [an atom], but scientists can see it . . . by the microscope for tiny things, other than the one in the laboratory" (E8, preinterview). Similarly, 50% of all participants seemed to believe that scientists were certain about the way dinosaurs look like because scientists have seen dinosaurs: "Scientists could tell how the dinosaurs look like because they saw frozen dinosaurs in the North Pole" (E25, prequestionnaire).

Indeed, on further probing during interviews, many participants did not seem to comprehend the distinction between the way scientists depict the appearance of dinosaurs (inference) and fossilized bones on which such depictions are based (observation). For instance, after having acknowledged interviewees' responses that scientists put fossilized bones together to get an idea about the way dinosaur skeletons look like, the researcher asked interviewees, "But how do scientists get to know, for example, about the color of dinosaurs?" A typical response would be, "As I said before, when scientists find bones they put them together to know how the dinosaurs look like . . . like his arms, legs, head, eyes" (I14, preinterview).

In the case of dinosaurs, only 8% of students demonstrated an understanding of the distinction between what is observed (fossils) and what is inferred (appearance):

> Scientists saw the bones, put them together . . . and they took shapes from animals. For example, they put the colors of dinosaur from the snake . . . maybe its color is not like this but they put for it a suitable color. They chose for it skin like the skin of crocodiles, they chose from wild animals . . . they are not much certain because it may be wrong. (I2, preinterview)

However, none of the participants noted that scientists learn about the atomic nature of matter through indirect evidence.

The Empirical Nature of Scientific Knowledge. A total of 84% of participants expressed naive views of the empirical NOS. As noted earlier, 45% of participants equated knowing with seeing. These participants made no distinction between evidence and knowledge, thus failing to discern that claims about natural phenomena could have some merit because they are based on evidence even though scientists were not able to see directly how these phenomena work. Indeed, in their responses to the multipart questionnaire item about dinosaurs, 58% of participants did not demonstrate adequate understandings of the role of evidence in generating images for dinosaurs, which they believed ''comes from their [scientists'] fantasy . . . There is no evidence that make them know because scientists did not see the dinosaurs to know what the dinosaurs' body looks like'' (E13, preinterview).

By comparison, 8% of participants elucidated more informed conceptions of the role of evidence in generating scientific claims. They noted that even though scientists did not see dinosaurs, they were able to generate somewhat accurate images of dinosaurs because those images are based on fossil remains:

> [Scientists are] 60% certain because the shape of dinosaurs is not complete. . . . Because dinosaur bones are very big, they knew they are very big. If their bones are like this, then they would be very big; that's how they know how they look. (I7, preinterview)

However, none of the participants' preinstruction responses alluded to the crucial role that evidence plays in modifying and rejecting scientific knowledge.

The Role of Imagination and Creativity in Generating Scientific Knowledge. Eighty-two percent of participants expressed naive views regarding the imaginative and creative NOS. There were three major trends in participants' views. First, as noted earlier, 45% of participants noted that scientists learn about the atomic nature of matter by observing atoms under microscopes. Second, 40% of participants did not seem to perceive that imaginative and creative work could be involved in depicting how dinosaurs look. They simply indicated that scientists have seen dinosaurs or pictures of them. By comparison, only 5% of participants indicated that scientists use imagination and creativity to generate knowledge, such as depicting the structure of matter or the appearance of dinosaurs:

> Scientists imagined it like this, they gave matter this structure. Maybe it's not true . . . They imagined it like this because scientists didn't see atoms. (I2, prequestionnaire)

> Scientists put the [dinosaurs] skeletons together. . . . Their colors are from their minds, from their inventions. These are inventions of scientists because they don't know this. They only know their skeletons . . . the skin on their bodies is all from their imaginations. (E2, preinterview)

Third, in their responses to the last item on the questionnaire, which specifically asked whether scientists use imagination and creativity in their work, 48% of participants noted that science could never involve human aspects, such as imagination and creativity, because this would result in incorrect or wrong findings and knowledge:

> No, scientists do not use them [imagination and creativity] in their investigations or experiments, because it is not possible that children study something from the scientists' imagination. (E14, preinterview)

> No, because imagination and creativity make one imagine, it's not true since one cannot imagine the true things. . . . Like, scientists were sure this was the shape of dinosaurs, they cannot change their minds. (I33, preinterview)

A total of 13% of participants indicated that scientists use imagination and creativity in their work. However, these participants used the terms *imagination* and *creativity* to refer to aspects and activities different from those related to generating knowledge or ideas. The fourth and fifth items on the questionnaire asked participants to elucidate what they mean by these terms and provide examples to clarify their views. The majority of participants (82%), including the above 13%, seemed to equate the terms "imagination" and "creativity" in science with the ability to make one's scientific product or experiment attractive, or to be able to write lucidly:

> When the scientist makes something, he will be creative to be able to write all the information. (I15, prequestionnaire)

> The scientist has skills; he has creativity to get the experiment good and nice for people to see. (E24, preinterview)

Participants' Postinstruction Views of NOS

Table 3 (Columns 3 and 7) indicates that the postinstruction NOS views of participants in the implicit group were not different from their preinstruction views in any substantial way with the exception of the distinction between observation and inference. Compared with 7% of the implicit group participants at the outset of the intervention, more than twice as many participants (18%) elucidated more adequate views of this NOS aspect at the conclusion of the study. This change could be attributed to the fact that science process skills instruction involves making observations and inferences, and explicitly labeling these activities as such. Moreover, in response to student questions or to avoid confusion, sometimes differences between observation and inference were highlighted. Some students seemed to have internalized this distinction even without providing them with structured opportunities or experiences to discern the observable versus inferential nature of claims they might make in the course of an inquiry activity, and the consequences of such differences regarding the validity of these claims. Nonetheless, the percentage of the implicit group participants who elucidated informed views of the inferential NOS (an additional 11%) remains fairly unsubstantial especially compared with changes in explicit group participants' views in this regard (an additional 31%).

Moreover, Table 3 indicates that the explicit group participants achieved substantial gains in their conceptions of the target NOS aspects. The following discussion highlights changes that were evident in these participants' NOS views relative to their preinstruction conceptions. A notable pattern in the explicit group participants' postinstruction NOS views was that students were able to articulate more informed views of the target NOS aspects in the context of discussing dinosaurs compared with discussing the atomic nature of matter.

The Tentative Nature of Scientific Knowledge. Compared with 6% at the beginning of the study, 52% of the explicit group participants articulated informed views of the tentative NOS at its conclusion. In their postinstruction responses, these participants noted that scientific knowledge in their textbooks can change either ‘‘because scientists find another or new evidence’’ (E25, postquestionnaire) or ‘‘because scientists cannot be very certain all the time. Scientists do not see all things, but they infer and imagine . . . they may be mistaken’’ (E21, postquestionnaire).

Indeed, in their postinstruction responses to the dinosaurs item, 48% of participants noted that scientific knowledge might change if and when new evidence is brought to bear:

> Yes, the way the dinosaur looks may change because, like, if they brought something to put together and, for example, it turned out to be the bone of a dog, then later they brought another bone and it turned out to be fitting better for the dinosaur, it [the dinosaur shape] will change. (E18, postinterview)

Moreover, 30% and 43% of participants, respectively, in the explicit group noted that scientists are not certain about atomic structure and the way dinosaurs look. These participants noted that such claims could not be ‘‘100% certain . . . because scientists use their imagination and creativity’’ (E29, postquestionnaire):

> [Scientists] are not certain . . . they did not see it [the atom]. But they would be a little sure, because they did experiments . . . For example, Rutherford did an experiment and he inferred that there is something concentrated in the center; he called this the nucleus. (E22, postinterview)

Distinction Between Observation and Inference. Compared with only 9% at the beginning of the study, 40% of participants in the explicit group demonstrated adequate views of the distinction between observation and inference at its conclusion. These participants noted that scientists use inferences to determine atomic structure because atoms cannot be observed:

> Scientists can’t be certain because they didn’t observe atoms, they only inferred that it exists. Example: like when we did the thing about the box [referring to the black box activity used to demonstrate Rutherford’s experiments], we know there is something in the middle of the box, but we didn’t observe it we inferred it only. (E19, postquestionnaire)

Similarly, these participants explicitly indicated that scientists use inference to depict how dinosaurs look as evident in the following representative quotation:

> Well, every time they find a bone, they will get a shape. . . . For example, they get from one dinosaur a part, from another they get the parts of mouth and hands, from another they get the shape of feet and body. They put them together to infer the shape of dinosaur. . . . Maybe this is its shape and maybe not. (E26, postinterview)

The Empirical Nature of Scientific Knowledge. At the outset of the study, only 6% of participants in the explicit group expressed informed views of the empirical NOS. None of these participants, however, elucidated a role for evidence in changing scientific knowledge. After the intervention, 48% of the explicit group participants indicated that scientific knowledge might change if new evidence is brought to bear:

> Yes [scientific knowledge might change], because if they found something new they will change their minds and they will make the new thing, which they have newly found. Example, in fossils if they will find something new they will change the dinosaur. (E17, postquestionnaire)

Moreover, after the intervention, 30% of the explicit group participants elucidated informed conceptions of the role of evidence in depicting atomic structure:

> Rutherford . . . directed a beam of particles in a very thin sheet of gold. He observed that some particles go through the sheet and few not. This made him to infer that some particles concentrated in the center and he called these particles nucleus. From that we know that scientific knowledge may change because he inferred what was inside the atom and if scientists made an experiment and observed something new they can change it. (E31, postquestionnaire)

Similar understandings were expressed by participants in the explicit group in the context of discussing the dinosaurs. These participants noted that even though scientists imagine the way dinosaurs look, they still have to check their imaginations against evidence:

> They imagine its shape; every scientist would imagine a shape and finally each one will give the one he imagined . . . Then they will see whether the dinosaur they imagined matches the bones. (E14, postquestionnaire)

The Role of Imagination and Creativity in Generating Scientific Knowledge. Relative to 3% at the outset of the study, 34% of the explicit group participants articulated informed views of the creative and imaginative NOS at its conclusion. However, more participants expressed informed views of this NOS aspect in the context of discussing dinosaurs compared with discussing the atomic nature of matter. Only 15% of participants in the explicit group noted that scientists "used their imagination when they thought about this structure of matter" (E9, postquestionnaire). By comparison, 28% of the explicit group participants demonstrated informed understandings of the creative and imaginative NOS when discussing how scientists depict the way dinosaurs look: "They [scientists] use their observation to tell how a dinosaur look like and also they use their imagination and creativity to tell how the dinosaurs look like" (E34, postquestionnaire). Finally, at the conclusion of the study, 34% of the explicit group participants explicitly noted that imagination and creativity play a role in scientific investigations:

> Of course, scientists use their imaginations and creativities in their investigations and experiments. Example: Scientists use their imaginations and creativities when they work with fossils to infer this organ to what kind of animals belong to. (E17, postquestionnaire)

Discussion and Implications

At the outset of the present study, a majority of participants (85%) held naive views of the four target NOS aspects. These results are consistent with ones from previous research studies that assessed elementary and middle school students' views of NOS (e.g., Bady, 1979; BouJaoude, 1996; Smith et al., 2000; Meichtry, 1992). These and similar results indicate that much is still desired in terms of helping elementary and middle school students develop informed views of some aspects of NOS.

The present results indicate that an explicit and reflective inquiry-oriented approach is more effective than an implicit inquiry-oriented approach in enhancing sixth graders' views of the target NOS aspects. The views of the implicit group participants, who were engaged in inquiry activities that also emphasized science content and process skills, were not enhanced in any substantial way at the conclusion of the study. By comparison, the postinstruction views explicated by 52%, 48%, 40%, and 34% of the explicit group participants were consistent with current conceptions of the tentative, empirical, inferential, and imaginative and creative NOS, respectively. This improvement is substantial given that only 6% of these latter participants held informed views at the beginning of the study.

That participants in the implicit group did not substantially improve in their NOS understandings was anticipated. This finding is consistent with ones reported by researchers such as McComas (1993), Meichtry (1992), and Moss et al. (1998), who used inquiry-oriented and/or science process skills instruction in their attempts to enhance learners' NOS views. These results should not be surprising. After all, engaging in inquiry and learning about science process skills are not equivalent to learning about NOS. These three aspects of science are necessarily interrelated and interact in important ways. However, there are important distinctions among these aspects that are often conflated in the literature. Learning to make careful observations is an important science process skill. Nonetheless, mastering such a skill does not automatically lead to understanding that observations are necessarily constrained by our perceptual apparatus and guiding conceptual frameworks. This latter understanding belongs to the domain of NOS. In a similar fashion, controlling variables is an integrated science process skill essential to conducting scientific inquiry. However, learning about and practicing this skill does not necessarily entail learning about the logic of experimentation that also belongs to the realm of NOS. Indeed, the present results do not lend empirical support to the assumption underlying the implicit approach, namely, that student would necessarily develop better NOS understandings as a result of engagement in inquiry activities or science process skills instruction.

It follows that if students are to develop informed NOS conceptions, explicit-reflective instruction geared toward that end should be used. This is not to say that inquiry-oriented teaching or science process skills instruction is not important. It is the researchers' belief that attempts to teach about NOS should be contextualized and woven into inquiry activities and teaching about science content and process skills. Actually, as explained above, all the inquiry activities used in the present study were geared toward regular sixth-grade science content. The activities in both the implicit and explicit groups emphasized content and science process skills. However, as was evident from the implicit group postinstruction responses, such emphases did not result in better understandings of relevant NOS aspects. By comparison, when the same activities were coupled with structured opportunities for students to reflect on what they did in those activities from within a framework of the target NOS aspects, the results were more positive. It seems that treating NOS as a cognitive instructional outcome, with the consequence that specific instructional activities are geared toward teaching such an outcome, might enhance the possibility of success for the attempts undertaken to improve students' NOS views.

However, even with an explicit and reflective approach, much is still desired. First, the intervention was successful in influencing the views of about 50% of the explicit group participants. Second, the views of only 24% of the explicit group participants were improved with regard to all four target NOS aspects. The remaining participants internalized informed views of 3 (34%), 2 (45%), or even 1 (52%) of these aspects. In this regard, it is noteworthy that almost all participants who expressed informed views of the empirical nature of scientific knowledge also expressed informed views of its tentativeness. Moreover, it seemed that developing an understanding of the creative and imaginative NOS was not an easy undertaking for the participants. After all, developing an understanding of this NOS aspect entails viewing knowledge as a human construction that is built rather than discovered by scientists. Eleven-year-old students might not easily attain such a view of knowledge generation. Thus, only a minority of the explicit group participants (24%) achieved consistent and integrated understandings of the four target NOS aspects. Moreover, no change whatsoever was evident in the views of about one-half of the explicit group participants at the conclusion of the study.

Based on the literature (e.g., Abd-El-Khalick & Lederman, 2000; Driver, Leach, Millar, & Scott, 1996) and our experiences with improving learners' views of NOS, we believe that three factors largely influenced the present results. The first is the duration of the intervention. Participants in the explicit group were instructed for two 50-minute sessions per week over the course of 10 weeks. Their views of NOS have developed over the course of at least 5 years of formal science instruction. These views, as was evident from analyzing preinstruction data, were mostly inconsistent with current NOS conceptions. It would prove difficult to change such views over the course of 2.5 months. The second factor is related to the tenacity with which students hold on to their views of content in general and NOS in particular. The research on students' naive or alternative conceptions of science is too well known to be reiterated here. Suffice it to say that changing students' views of science content or NOS has been shown to be a difficult and involved process (Driver et al., 1996; Wandersee, Mintzes, & Novak, 1994). The third factor relates to context: It seems that changes in students' NOS views depend on the content and context within which these views are presented and learned. In the present study, more participants explicated informed views of the empirical, tentative, inferential, and imaginative and creative NOS in their discussions of dinosaurs compared with their discussions of the atomic structure of matter. Views of NOS and conceptions of science content or the complexity of this content seem to interact in major ways. Participants were able to make sense of the target NOS aspects in a context that was more relevant and interesting to them (i.e., dinosaurs) compared with more abstract and complex subject matter (i.e., structure of matter).

One possible way to improve the effectiveness of an explicit and reflective approach is to implement the approach within a conceptual change framework (Posner, Strike, Hewson, & Gertzog, 1982) In such an approach, in addition to eliciting students' views of the target NOS aspects, instruction would start by making students aware of their own views. Next, purposeful activities and/or discussions would be undertaken to render students dissatisfied with their naive views. Science instruction would follow in which inquiry and other science-based activities are coupled with a structured NOS reflective component of the type undertaken in the present study. Next, participants should be provided opportunities to apply their acquired NOS understandings to novel contexts for them to appreciate the applicability and fruitfulness of such understandings in making sense of the development and characteristics of scientific knowledge. Examination of brief historic case studies would serve as a good candidate to achieve this instructional component. Moreover, when examining such case studies, students should be encouraged to contemplate connections among the target NOS aspects for the purpose of helping them develop integrated understandings of their acquired NOS views, and a consistent overarching framework for them.

Moreover, the present study indicates that students' NOS views could be enhanced when the target NOS aspects are embedded and taught within a framework of content-related inquiry activities. These activities serve to contextualize these NOS aspects and make them accessible to students. Indeed, inquiry can be thought of as a bridge or a base upon which NOS instruction could be built. Nonetheless, inquiry by itself seems insufficient to teach students about NOS.

In addition, given that time might have been a restrictive factor in promoting change in students' NOS understandings in this study, explicit and reflective NOS instruction needs to be incorporated throughout science teaching over an extended period of time. Students' views that were developed over years of formal science instruction should be offered generous time to change. It follows that extensive curricular and pedagogic changes are needed to include NOS understandings not as hoped-for by-products of inquiry teaching but as cognitive outcomes that are intentionally taught in the context of inquiry activities which address regular science content. In this regard, the reader is reminded of the extended discussion of the characteristics of an explicit and reflective approach presented at the outset of this report. In particular, this approach should not be confused with didactic teaching or construed from within the narrow perspective of the generic strategies collectively referred to as explicit teaching.

Finally, this study suggests some fruitful venues for future research. First, the present results are limited to the participants and context within which the study was conducted. Participants were not intended to be representative of a larger population. More research into the relative effectiveness of an explicit and reflective inquiry-oriented approach on students' NOS views at different grade levels and in different contexts needs to be pursued to establish the validity and generalizability of the present results. Second, it was argued that the effectiveness of an explicit and reflective approach might be enhanced if implemented within a conceptual change framework. Research into the effectiveness of such an approach might be fruitful. Third, given that developing NOS understandings seems to interact with the kind of content within which NOS instruction is embedded, research that establishes and elaborates our understanding of this interaction might enhance the likelihood of the success of any attempts undertaken to enhance students' NOS views.

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