Early Elementary Students' and Teacher's Understandings of Nature of Science and Scientific Inquiry: Lessons Learned From Project ICAN

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Abstract

Effective instruction related to nature of science (NOS) and scientific inquiry (SI) require teachers to develop a knowledge base as well as purposeful intentions to address NOS and SI within classroom instruction. Project ICAN: Inquiry, Context, and Nature of Science, an NSF-funded teacher enhancement project, aims to enhance teachers' abilities to improve students' understanding of NOS and students' understanding of, and ability to perform SI, within a context of standards-based instruction. In its third year, 58 teacher-participants participated in the project that included three phases with the following sequence: summer orientation, monthly academic year workshops, and a three-week summer institute. Questionnaires, video-taped lessons, lesson plans, instructional materials/assessments, classroom observations, and student achievement comprised the data for examining the teaching and learning of NOS and SI. Participants demonstrated major enhancements in their understandings and their classroom applications of NOS as demonstrated in gains in their students' views. This report focuses on a case study of the knowledge and progress of a grades 1-2 teacher and the subsequent learning of her students. The particular reason for focusing on this case study is the continuing debate about the developmental appropriateness of NOS and SI outcomes for early elementary level students.

INTRODUCTION

Students' understandings of science and its processes beyond knowledge of scientific concepts have been emphasized in the current reform efforts in science education (AAAS, 1993; NRC, 1996; NSTA, 1989). In particular, the National Science Education Standards (1996) state that students should understand and be able to conduct a scientific investigation. The Benchmarks for Science Literacy (AAAS, 1993) advocates an in-depth understanding of scientific inquiry (SI) and the assumptions inherent to the process. Both reform documents consistently support the importance of students' possessing adequate understandings of nature of science (NOS). Research, however, has shown that teachers do not possess adequate views of NOS and SI that are consistent with those advocated in reform documents. Moreover, it is difficult for teachers to create classroom environments that help students develop adequate understandings of NOS and SI (Lederman, 1992; McComas, 1998; Minstrell & van Zee, 2000) without explicit instruction and assessment.

Nature of Science

NOS refers to the values and beliefs inherent to scientific knowledge and its development (Lederman, 1992). Although disagreements exist among philosophers of science, historians of science, scientists, and science educators regarding a universal definition for NOS, these disagreements are irrelevant to K-12 students (Abd-El-Khalick, Bell, & Lederman, 2000). It can be argued that the seven aspects of NOS referred to in this investigation are accessible to and relevant to K-12 students’ everyday lives. It can further be argued that the aspects are at a level of generality that avoids any contentious arguments. The aspects of NOS referred to here involve an understanding that scientific knowledge is tentative, subjective, empirically based, socially embedded, and depends on human imagination and creativity. Two additional aspects involve the distinction between observation and inference and the distinction between theories and laws.

Scientific Inquiry

The NSES, (NRC, 1996) states that “Students will engage in selected aspects of inquiry as they learn the scientific way of knowing the natural world, but they also should develop the capacity to conduct complete inquiries.” (p. 23) In addition to being able to conduct inquiries of various types, the NSES also promote students’ understanding about scientific inquiry (NRC, 2000). This understanding includes

- knowledge about various methods of investigation (there is no single "scientific method"),
- understanding of the placement, design and interpretation of investigations within research agendas (current knowledge and direction guide investigations),
- recognition of assumptions involved in formulating and conducting scientific inquiries,
- recognition of limitations of data collection and analysis in addressing research questions,
- recognition and analysis of alternative explanations and models,
- understanding of the reasons behind the use of controls and variables in experiments,
- understanding of distinctions between data and evidence,
- understanding of relationships between evidence and explanations and the reliance on logically consistent arguments (based on historical and current scientific knowledge) to connect the two,

- understanding of the role of communication in the development and acceptance of scientific information

Research has shown that through explicit/reflective instruction, aspects of NOS and connections of these aspects within the context of science activities, students are able to understand the aspects of NOS (Abd-El-Khalick & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002; Smith, Maclin, Houghton, & Hennessey, 2000). An explicit/reflective approach draws learners' attention to relevant aspects of NOS and SI in the context of inquiry-based activities or historical examples. The design of Project ICAN has been systematically derived from this research.

Project ICAN

Project ICAN (Inquiry, Context, and Nature of Science) is an NSF Teacher Enhancement grant that focuses on the development and implementation of a professional development model to enhance middle and high school science teachers' disciplinary and pedagogical knowledge related to unifying concepts, SI and NOS. The goal of the Project is to enhance teachers' abilities to improve students' understanding of NOS and students' understanding of, and ability to perform SI, within a context of a standards-based science curriculum. Previous efforts have focused on either teacher knowledge or student achievement relative to SI and NOS. Project ICAN represents a first attempt to connect teachers' professional development and knowledge relative to NOS and SI, classroom practice, and student achievement.

The third year of the project, described in this paper, was conducted with 58 teacher-participants. All seven of the previously discussed aspects of NOS were emphasized in the project. These include understanding that scientific knowledge is tentative, empirically based, subjective, depends on human creativity, involves a combination of observation and inference, and culturally embedded. In addition, the distinction between scientific laws and theories was emphasized. Although 58 teachers were involved in the project, this report focuses on a case study of one grade 1/2 teacher and her 26 students. Results for the full set of 58 teachers and their students are reported elsewhere (Lederman, Lederman, Khishfe, Druger, Gnoffo, & Tantoco, 2003).

METHOD

Project ICAN consisted of the following sequence of activities: a summer orientation, monthly academic year workshops, and a two-week summer institute.

Summer Orientation

During this one week orientation, teachers were provided with introductory background concerning the rationale for the project and its organization. Initial understandings of NOS and SI were developed through a series of investigations and activities followed by explicit and reflective de-briefings of activities. Again, this short orientation was designed to provide an overall framework for the project and to begin the long journey of developing teachers' understandings, changing of teaching practices, and subsequent enhancement of students' understandings.

Academic Year Activities

During the academic year, the 58 teachers participated in 10 full-day monthly workshops. These workshops included NOS and SI instruction, reflective review of participants' instructional experiences and teaching videos, and curriculum revision. Teachers actively engaged in SI activities and NOS activities. Some of these activities include "tricky tracks," "fossils," "mystery bones," "the tube," and others. Detailed descriptions of these NOS activities, as well as others, can be found elsewhere (Lederman & Abd-El-Khalick, 1998). All teachers videotaped at least one lesson for the project staff to review and provide feedback prior to each of the workshops. A selection of videotaped lessons was chosen to view as a group at the monthly workshops. This approach provided the group opportunities to discuss each other's teaching and teaching contexts, offer peer support and feedback, and see growth in their own and other's teaching. Monthly workshops also addressed NOS and SI instruction in the context of science subject matter, curriculum revision, and viewing/debriefing teachers' videotaped lessons. Teachers shared lessons and reported outcomes during the workshops. In addition, teachers focused on revising lessons to explicitly teach about NOS and SI within the context of "traditional" science subject matter. All lessons were followed by group debriefings to discuss successes, challenges, and extensions to the activities.

During the academic year, teachers also engaged in authentic research internships, the purpose of which was to incorporate information from actual research experiences into classroom instruction. Teachers engaged science research internships with practicing scientists located in university laboratories or in informal education institutions such as natural history museums and zoos. The aim of the research experience was to enhance teachers' understandings of inquiry and NOS within an authentic context.

Summer Institute

During the two summer weeks, teachers participated in 10, six-hour sessions that focused on NOS, SI, and unified concepts through a series of explicit/reflective activities, readings, and discussions. NOS and SI were contextualized within standards-based science subject matter. These sessions targeted a variety of areas. Focus questions and journal responses served to guide group discussions for reflection, comparison among research experiences, and sharing of ideas to establish connections between the research settings, aspects of NOS, SI, and classroom applications. Again, teachers engaged in revising lessons to teach about NOS and SI in an explicit manner within the context of traditional science subject matter. Additionally, the summer institute focused on the development of performance-based assessments for scientific inquiry and nature of science.

DATA SOURCES AND ANALYSIS

Data addressing the change in teachers' views were collected during the orientation. Toward the end of the orientation, teachers completed two questionnaires: Views of Nature of Science (VNOS-D) and Views of Scientific Inquiry (VOSI). These questionnaires were administered twice during the year; at the beginning of the academic year and at the end of the summer institute.

The NOS aspects assessed include that science is: tentative, subjective, based on empirical observation, the product of human creativity, involves observation and inference, culturally embedded, as well as the distinction between theories and laws. Aspects of SI targeted on the VOSI include a) multiple methods and purposes of investigations, b) importance of consistency between evidence and conclusions, c) multiple interpretations of data are possible, d) distinctions between data and evidence, and e) data analysis is directed by the questions of interest, involves the development of patterns and explanations that are logically consistent. A representative sample of 10 teachers, based on their views of NOS and SI, was interviewed regarding their responses on the VNOS-D and VOSI. Profiles of teachers' views of NOS and SI aspects were generated based on their two VNOS and VOSI responses. Additional data sources included journal reflections and revised existing curricular materials, which were collected during the academic year. Developments in teachers' views were sought by comparison of profiles for each participant generated from VNOS and VOSI responses. Other data were examined for similar progress throughout the program to further inform the effectiveness of Project ICAN.

Video-taped lessons, lesson plans, instructional materials/assessments, and classroom observations comprised the data for examining the teaching of NOS and SI. Students' views of NOS and SI were assessed by the administration of the VNOS-D and the VOSI questionnaires (around 1500 students, grades K-12) to students. It is important to note that younger students (grades K-2) were asked to complete a specially produced set of questionnaires (i.e., VNOS-E and VOSI-E). These questionnaires were administered orally and can be found in the Appendix to this paper. Additional teacher developed classroom assessments that specifically addressed NOS or SI were examined to enrich the description of student outcomes. All of these data were collected prior to the end of the school year. Data were reviewed for explicit reference to NOS and SI. Data for each student were analyzed to provide details of students' views of the targeted aspects of NOS and SI.

Assessment Obstacles Specific to Primary Students

The previously used assessment instruments VNOS-D and VOSI proved problematic when administered to young children (grades K-2), for several reasons. The developmental level of the vocabulary was inappropriate for them to understand and some of the examples used to illustrate several aspects of NOS and scientific inquiry were not familiar to many of the students. Consequently, more appropriate instruments needed to be developed. The process began with a focus group of eight elementary level teachers from previous years of Project ICAN. These teachers had used both instruments with their students and were quite aware of the difficulties created by the language and examples. After an initial revision of the VNOS – D and VOSI, the teachers had classes of their students read the instruments for readability. Further revisions resulted from this process and the final versions used in this investigation can be found in the Appendix to this paper. Of course, at this point, only half of the task was completed. Many of the students to whom the instruments were to be administered were too young to read. So, although the language and examples were more developmentally appropriate, students' reading ability became the issue. Additionally, many of the students could nott write or were just learning to write and found it difficult to express all of their ideas on paper. The solution was clearly to use an oral administration of the instruments to small groups (i.e., five) of students and then record their answers. The decision to interview the students in small groups was based on time limitations as well as the problems with the dynamics of whole groups discussions with young children. The diversity of responses is much greater for young children in small groups than during whole class discussion. The class in this case consisted of 26 students in mixed grade level (1-2) class. There were 13 boys and 13 girls. The racial demographics of the class were: 16 Afro-American, 8 white, 1 middle eastern, 1 multiracial.

The first author met with four groups of five and one group of six students at the beginning of the school year. All sessions were audiotaped. Sitting on the floor in the hallway of the school, the first author asked the students the questions from the VNOS –

E and VOSI – E. Having students roll toward and away from you on a carpet as they compose thoughtful answers about the epistemology of science is a unique experience indeed. Often students offered answers to questions much later than they were asked. Young children often need time to inventory their thoughts about a topic before they can construct an answer. But once they do, their answers are focused, thoughtful and well developed. Young students also use body motions to help explain their thoughts. Some children have to stand up and use their arms and hands to illustrate their answers. Others jump up and role play their ideas. These gestures were also recorded along with the children's oral responses. The pre and posttests were administered in the same manner.

RESULTS

As stated previously, results for the entire cohort of Project ICAN teachers has been previously reported (Lederman, Lederman, Khishfe, Druger, Gnoffo, & Tantoco, 2003). What follows are the results of a case study with one grade 1-2 level teacher and her 26 students. The results of the case study are particularly enlightening with respect to the abilities of very young students and the assessment of NOS and SI with very young students. At this writing, a detailed description of very young students' understandings of NOS and SI, and its assessment with very young students, did not exist.

Change in Teacher's Views of Nature of Science and Scientific Inquiry

Overall, the teacher showed enhanced views of NOS conceptions. Although she initially showed naïve views of all aspects of NOS, she held informed views of at least four target aspects by the end of the ICAN project. Most significant were the changes in her views of the tentative, creative, subjective and empirical aspects of NOS. Many of the inquiry-based activities and group discussions during the ICAN meetings explicitly dealt with these aspects and helped teachers to integrate these aspects into their classroom instruction.

Following are quotations from her VNOS post-questionnaire concerning her views of the tentative aspect of NOS:

> “Their models [computer models of the weather patterns] are the best representation they can make at the time of what they understood.”

> “What may have been thought of as true in the past becomes subject to debate and sometimes is even tossed out.”

She also held informed views of the distinction between observation and inference. In reference to this aspect she wrote, “without directly observing what happened, scientists can only infer what happened.” and “we can only infer the actual appearance of the dinosaur.”

She exhibited informed views of the empirical aspect of NOS in her responses to the posttest. For example, she stated, “they [scientists] may find evidence that may cause a change in what was previously thought and found.”

She demonstrated informed views about the role of imagination and creativity, “scientists use creativity in planning their investigations and sometimes while analyzing their data.”

She also exhibited informed views of the subjective aspect of NOS. Prior to instruction, she believed that scientists reach different conclusions because they have different data “science is subjective in that each scientists has access to different data and evidence.” These responses changed drastically during the program. For example, during a follow-up interview to the post - questionnaire she said she believed that scientists disagree about what caused extinction of dinosaurs even though they all have the same information because “different people make different inferences based on their life experiences, education, and cultural surroundings.” Another response was, “They [scientists] draw conclusions based on their prior knowledge and collected data.”

With regard to scientific inquiry, she began the program with the view that inquiry involves a linear step-by-step process that, if followed, leads to the correct answer. She viewed the process as controlled and the scientist as objective. On the posttest questionnaire and interview she demonstrated major changes in these traditional views by recognizing that there is no universal step-by-step scientific method. She showed the greatest change in her views of scientific inquiry begins with a question and that procedures are guided by the question asked. Furthermore, she came to recognize multiple methods to conduct scientific investigations and that different scientists can have different methods for reaching conclusions. In her classroom, she conducted the inquiry-based activities that began with identified questions and reinforced multiple methods of investigations. She tried to suggest to her students that the there is no single way to do an investigation.

She advanced in her knowledge of multiple or alternative interpretations given a set of data. She came to understand that scientists can have different inferences due to “scientists’ creativity, culture, and differences;” and that the scientists often comes into the process with prior conceptions, past experiences, beliefs and values that affects how he/she looks, views, and interpret things. During an interview she said, “even if scientists are working together, subjectivity may play a strong role in formulating someone’s ideas and influence how results are looked at.”

The teacher advanced in her understanding of the importance of supporting conclusions with evidence, which corresponds to the empirical aspect of NOS. Many of the inquiry-based activities in ICAN as well as experiences in the science research settings reinforced the importance of basing conclusions on data. Again she attributed her success at understanding this aspect to her understanding of similar concepts in language arts. Once she recognized the commonalities in the two disciplines, the importance of evidence in language arts and evidence based conclusions in science became obvious.

Instructional Practices

At first, the teacher expressed concerns about explicitly addressing NOS or SI in her science instruction because she was unsure about her own understandings of these areas and also because her science instruction in the past was primarily exploration based. She explained she would set up science discovery centers and allowed students to spend time freely exploring materials and phenomena and making their own observations. She would ask students leading questions but most often left them to explore on their own or in small groups. The science discovery center changed several times during the school year. The topics included sink and float, magnets, and balls rolling down ramps. She slowly created lessons at these stations that involved students in asking questions, making predictions, designing ways to answer their questions, recording observations and data and coming to conclusions. Gradually, she started integrating explicit NOS and SI into her science activities and lessons. When the connections between her methods of teaching language arts and inquiry based science became apparent, she became even more comfortable and confident with her science instruction. Since she viewed herself as a very successful language arts teacher, this connection between language arts and science supplied the impetus for her to try new approaches to her science instruction and the ICAN workshops gave her the continued support throughout the school year. She attributed her success at teaching that conclusions need to be based on evidence to her successful teaching of similar concepts in language arts. It was an easy transition from teaching about the difference between, opinion, facts and evidence in reading, to the idea of evidence based conclusions in science. Because her students were already accustomed to providing evidence for their conclusions about stories they read or listened to, they easily came to understand that they needed to provide similar evidence based conclusions for science investigations and demonstrated informed views of this aspect on the posttests. This was one area she felt confident about explicitly addressing in her science instruction since she already did this in her language arts instruction practices. Students' ideas and opinions were often addressed in her reading and process writing lessons.

Changes in Students' Views of Nature of Science and Scientific Inquiry

Pretest data indicated that, overall, the students demonstrated naïve views of NOS and SI. During the academic year, the teacher explicitly discussed the tentative, inferential, empirical, subjective and creative aspects of NOS. Ten of the students showed more informed views of these four aspects of NOS. Seventeen of the students showed more informed views of at least two NOS aspects. The most significant changes in students' views were with respect to the subjective, empirical, and inferential aspects of NOS. The teacher also held informed views of these aspects and was more able to explicitly integrate them more frequently than other aspects. Instructional approaches included small group discussions within the context of science center activities and whole group inquiry-based investigations.

Nineteen of the students demonstrated major changes in their views of SI. None of the students held views that there was only one way to do science nor had they ever heard of the "Scientific Method." However, during the pretest interviews when asked what do scientists do when they do their work, many said that scientists "explode things" or "make potions" or "they experiment." Another student said, " They want to do a big test so they can work on it." When asked is they were doing science in class many responded, "No". One student said, "No, because we are just looking at things and we don't make anything explode." However, during the posttest interview, when asked what work do scientists do one child said, " They ask questions and then try to answer them." Another student said, "They dig up bones and then try to put them together into dinosaurs." When asked if they were doing science in class, 21 of the students responded "Yes." One student said, " Yes, because we are looking and seeing and thinking. Another child said, "Yes, we are watching the frog eggs hatch in the tank and we are predicting if the new parts are legs, tails or just poop, then we keep looking to see what happens."

Twenty-two of the students had more informed views of the multiple interpretations of a given set of data. When asked why students who investigated the same question had different conclusions one student said, " We just think different." Another student said, "Nobody did anything wrong, we just looked at things different."

Fifteen of the students had informed views about relationships between evidence and explanations and the reliance on logically consistent arguments to connect the two. When asked what people would say if I announced that I knew what caused the dinosaurs to die, several students said, “You would need proof!” or “How could you prove it? What new things did you find? More bones?” On a lighter note, one student said, “Tell them to believe you because you have the children on your side!”

CONCLUSIONS AND IMPLICATIONS

The teacher showed improvement in her views and abilities to explicitly teach NOS and SI within the context of primary level science instruction. However, changing teachers’ views is necessary but not sufficient to change their students’ views. Teachers’ intentions to integrate NOS and SI into their classroom practices are critical. All too often we assume that teachers’ knowledge and beliefs are automatically and necessarily translated into classroom practice. Research does not support this seemingly intuitive assumption when it comes to understandings about NOS and SI. Rather, it is important to realize that teachers teach what they value and, at this time, most teachers do not give NOS and SI a status equal to that of “traditional subject matter. Equally important is providing teachers who do not recognize themselves exclusively as science teachers with the content and pedagogical knowledge to teach inquiry based science in the first place. Peer group support and interaction in the monthly workshops proved to be an integral factor in all of the teachers’ development of PCK for NOS and SI.

The teacher’s and her grades 1-2 level students’ views of the inferential, empirical, creative, and subjective aspects of NOS improved greatly . These aspects appeared to be more easily integrated into the teacher’s classroom practice, as they can match with a wide range of contexts. These results indicate that the content/context might have a critical influence in teaching NOS and SI to young children. Moreover, the results from other teachers in grades 2 through 11 suggest that grade level might also determine the ease of integrating NOS and SI into the regular science lessons.

The results of this project clearly indicate that explicit instruction and continuing teacher support can develop the knowledge, instructional skills, and values teachers need to enhance young students' understanding of nature of science and scientific inquiry. It should be recognized, however, that the professional development required takes an extended and continuous period of time. Single point-in-time efforts with no follow-up support do little to help our classroom teachers implement the visions of reform. More importantly, this particular case study clearly indicates that very young students are capable of developing functional understandings of ideas as abstract as nature of science and scientific inquiry. Prior to this investigation, little evidence existed to support the idea that young students could show the knowledge gains illustrated here. Perhaps, a valid approach to assessing the understandings of students too young to read and write presented too much of an obstacle for such data to be collected. The VNOS-E and VOSI-E appear to be quite promising as orally administered assessments. Naturally, further research is needed that is conducted by individuals with experience in working with young students.

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