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The Influence of Guided Inquiry and Explicit Instruction on K–6 Teachers' Views of Nature of Science

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Abstract This study assessed the influence of guided inquiry and explicit reflective instruction on K-6 teachers' views of nature of science (NOS). Using the Views of Nature of Science Elementary School Version 2 (VNOS-D2), and associated interviews we tracked the changes in NOS views of teacher participants prior to and following a summer professional development program. The teachers participated in guided inquiry to improve physics knowledge, and explicit-reflective NOS activities to improve their views of NOS. Videotaped records of the workshop ensured that explicit reflective NOS instruction took place in conjunction with physics inquiry instruction. Analysis indicated that teachers improved their NOS views by the conclusion of the institute Implications for providing professional development combining inquiry and NOS instruction are made.

Keywords Nature of science · Inquiry · Professional development · Science · Physics · Elementary

Introduction

An appropriate understanding of the nature of science (NOS) has been linked to the development of scientific literacy (DeBoer 1991). Previous research has shown that teachers' views of the NOS are not consistent with contemporary conceptions of the scientific endeavor (Abd-El-Khalick and Lederman 2000; Gallagher 1991; King

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1991; Lederman 1992). National reform documents, such as *National Science Education Standards* (National Research Council [NRC] 1996) and *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS] 1993), have recommend that teachers help K–12 students to not only acquire understandings of scientific knowledge and develop skills needed to conduct scientific inquiries, but also to achieve an understanding of the NOS. However, without appropriate views of the NOS, teachers surely will not be able to achieve such an undertaking. Teachers possess many misconceptions about the NOS (McComas 1996), and these ideas may present barriers to effective science instruction. Various approaches have been undertaken to enhance teachers' views of several important aspects of the NOS, with differing levels of success. One line of research has been exploring the relationship between "doing science," inquiry, and understanding the NOS. Simply doing inquiry-based activities, the implicit approach, is not sufficient to enhance teachers' images of the nature of science (Abd-El-Khalick and Lederman 2000; Akerson et al. 2003). Of particular interest to those who work with practicing elementary teachers are professional development programs that provide instruction through explicit–reflective means. The explicit–reflective approach has been found to be successful in improving elementary teachers' views of the nature of science (Akerson and Abd-El-Khalick 2003; Akerson et al. 2000). Schwartz et al. (2004) found that an authentic scientific inquiry context, coupled with explicit–reflective NOS instruction, was effective in improving most secondary teachers' views of the nature of science. The current study describes the influences of a K–6 professional development program on NOS views of elementary teachers that combines explicit–reflective NOS instruction bridged to scientific inquiry in physics. The premise of our research design is that pairing scientific inquiry with NOS activities would assist participants in conceptualizing how NOS topics are a model of scientific inquiry when approached through an explicit–reflective method of instruction. Many teachers have misconceptions of inquiry and how science operates (NRC 2000). Many times these ideas are based on their previous science experiences. These experiences, usually more teacher centered or textbook based, provide a model as to correct science teaching practices. Because such misconceptions are steadfast and resistant to change, an effective way is needed for teachers to change their current conceptions. By pairing inquiry-based content instruction with explicit–reflective NOS instruction, the teachers see NOS aspects illustrated and practiced within the science content. Seeing science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge (Lederman 1992), may be necessary for teachers to understand science as inquiry. Through inquiry practices, coupled with explicit–reflective NOS instruction, teachers may be able to better recognize and understand aspects of the NOS.

Physics Emphasis

It has been shown that elementary teachers generally do not have a solid understanding of science content and, in particular, exhibit misconceptions in physics (Kruger and Summers 1989; Kruger et al. 1992; Lawrenz 1986; Smith and

Neale 1989). Special science courses designed specifically for teachers may be the best way to help teachers both understand and teach physics content, and this can be done without "watering down" the content (McDermott 1990; McDermott and DeWater 2000; McDermott et al. 2000). For this study, we used *Physics by Inquiry* (McDermott et al. 1996), which is a guided-inquiry program designed especially for teachers to teach physics through inquiry.

Inquiry and Nature of Science

The National Science Education Standards (NRC 1996) defines inquiry as "…the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (p 23). It may be difficult to prepare elementary teachers to use inquiry methods to teach science because many have not experienced inquiry instruction themselves as students (Kielborn and Gilmer 1999, Welch et al. 1981). We, therefore, use an inquiry-based program so teachers can experience inquiry for themselves, to help them clarify the meanings for themselves, and to see how much content they actually can learn through the method.

Some important aspects of the NOS are not controversial and have been advanced in recent reform documents (American Association for the Advancement of Science [AAAS] 1993, see Chapter 1; NRC 1996, see Chapter 6) and the position statement from National Science Teachers Association ([NSTA] 2000) for K–12 students. These aspects include the following: (a) Scientific knowledge is both reliable and tentative; (b) no single scientific method exists, but there are shared characteristics of scientific approaches to science (e.g., scientific explanations are supported by, and testable against, empirical observations of the natural world); (c) creativity plays a role in the development of scientific knowledge; (d) there is a crucial distinction between observations and inferences; (e) though science strives for objectivity, there is always an element of subjectivity (theory-ladeness) in the development of scientific knowledge; and (f) social and cultural contexts play a role in the development of scientific knowledge. Because teachers will be expected to help their own students understand these elements, these aspects are the target of the current project.

Explicit–Reflective Instruction

Prior research has shown explicit–reflective instruction is more effective in improving learners' understandings of the NOS than implicit instruction (e.g., Akerson et al. 2000; Khishfe and Abd-El-Khalick 2002). Explicit instruction refers to drawing the learner's attention to key aspects of the NOS through discussions and written work following engagement in hands-on activities. Reflective NOS instruction requires learners to think about how their work illustrates the NOS and how their inquiries are similar to or different from the work of scientists. Our study approaches explicit–reflective instruction with the idea that we specifically teach teachers the target NOS elements as part of the professional development program to sensitize them to the elements and make them aware of the ideas. Following their physics inquiries, we explicitly draw their attention to what they were doing in their investigations that illustrate NOS elements, asking them to reflect on how what they were doing was similar to or different from what scientists do in their inquiries.

Context of the Study

Seventeen K–6 elementary teachers participated in a 2-week summer workshop, of whom 14 consented to participate in the associated research. The workshop addressed two areas of professional development: (a) knowledge of physics concepts and (b) teaching techniques that explicitly emphasized the nature of science and scientific inquiry. *The Physics by Inquiry* curriculum (McDermott et al. 1996) was selected, with emphasis on the introductory units of mass and volume as a physics text.

The Participants

Teachers volunteered to participate in the workshop from three high-need school districts. The schools were chosen for their proximity to the research site and for meeting the following conditions: (a) Each district has greater than 20% of its students that qualify for free or reduced lunches, and (b) the superintendents indicated that the elementary science teachers in their districts have no special training for science teaching, with specialties generally in reading and language arts. Thus, they were teaching out of their preparation areas. Two of the districts are rural, with the third situated in a small metropolitan area.

The participants joined the program after responding to advertisements that were distributed within these three school districts. Teachers were accepted to the program after submitting an essay about what they hoped to gain from the program and their personal goals related to science in their classroom. While this paper reports on the first summer, participants committed to two 2-week, intensive summer workshops in successive years where they would participant in physics-content training, instruction in pedagogy, nature of science, inquiry, and how to incorporate standards into their instruction. Future interventions included monthly professional development days during the school year and one-on-one classroom support by the program staff. The content of the program was aligned with the state standard frameworks of the nature of science and technology, scientific thinking, the physical setting, and the mathematical world. Participants had opportunities to earn graduate credit or continuing education credit through their participation, and they were paid a stipend for their summer participation.

The participants varied in their science content backgrounds, with nearly all teachers taking fewer than 20 college science credits and general teaching experiences. The teachers' current assignments included three kindergarten, four second grade, one third grade, five fourth grade, one fifth grade, one sixth grade, a gifted and talented teacher, and a special education teacher. Participants' years of teaching experience ranged from 1.5–31 years. Most had taken biology in high school (16 of 17) and in college (14 of 17), but their background in physics was considerably less (4 of 17 with a high school background in physics and 6 of 17 with a college background). See Table 1 for further description.

The Institute

The 2-week summer professional development workshop took place in a university setting near all three school districts and consisted of two key components: (a) a morning session that focused on learning physics through inquiry and (b) afternoon sessions that emphasized pedagogy for teaching about physics, inquiry, and nature of science to elementary students. During each 3-hour morning session, the teachers constructed their physics-content knowledge using the *Physics by Inquiry* (McDermott et al. 1996) curriculum. This guided-inquiry program led the participants to build knowledge of various physics concepts. A physics graduate student provided content support. Each teacher pair worked through the inquiries at their own pace with no group-led discussion or introduction to the concepts. At predetermined intervals, usually after completing one or two inquiry activities, the teachers "checked out" with a staff member. These checkouts consisted of probing questions; no answers were given to the teachers, only more questions to extend their thinking or challenge their assumptions. For instance, in an inquiry about balancing a scale, many teachers assumed that the tabletop they were using was level. During the checkout, the teachers were asked to explain how they knew the tabletop was level and challenged to present evidence to support their assumptions. Once the teachers had answered the questions to the satisfaction of the facilitator, each pair was allowed to move to the next inquiry.

Afternoon sessions featured instruction and activities about the NOS and inquiry to familiarize teachers with the various NOS aspects as described in national reform documents (AAAS 1989, 1993; NRC 1996) and to give them strategies to

Table 1 Description of Participants Interviewed and Surveyed

Teacher	No. of science credits (college)	No. of years of experience	Current classroom assignment
Janet	12	28	4th gifted
Sally	15	7	4th
Mary	16	10	K
Kayla	12	31	K
Rebecca	12	14	4th
Amy	12	1.5	4th
Christine	12	5	2nd
Laura	15	10	6th
Lindsay	12	4	4th
Sam	20	8	5th
Latisha	12	6	2nd
Bette	18	2	K
Laurie	16	18	4th
Pam	12	19	2nd

incorporate the NOS and inquiry into their classroom instruction. Teachers were also asked to reflect on aspects of the NOS that were apparent in the morning sessions. Early in the workshop, efforts were made to acquaint the teachers with the various aspects of the NOS and inquiry. The teachers were led through non-content-specific activities, such as "Mystery Tubes," "Tricky Tracks," "Pattern Cubes," and "File Folders" as found in Lederman and Abd-El-Khalick (1998), to encourage them to explore their understandings and increase their content knowledge of the NOS. Black-box activities, which consist of investigations into mysteries that remain unseen to the naked eye**,** such as the mystery of the water-making machine, were shared with the teachers as they were challenged to recreate a model of the device and then describe the elements of the NOS that were illustrated by the activity. An activity that describes scientific investigations that led to the development of the atomic model called Rutherford's Enlarged (Abd-El-Khalick 2002) was presented in the workshop, with a historical perspective of Rutherford and his work added by the physics instructor. Additional illustrations of the NOS were found in children's literature. These books, such as in *Earthlets as Explained by Professor Xargle* (Willis and Ross 1994) and *Seven Blind Mice* (Young 2002), were shared with the group, along with how this literature strategy could be used to introduce and reinforce the NOS and inquiry concepts in the classroom. Other NOS activities included observations and inferences about similar objects and a fossil hunt activity that simulated an archeological dig. Workshop readings and class discussions allowed teachers to reflect on their developing understandings, enhanced their knowledge about the NOS, and shed light on many of the misconceptions of science (McComas 1996). Thus, we used an explicit and reflective approach to our NOS instruction (Akerson et al. 2000). Discussion encouraged teachers to identify NOS elements present, reflect on their use in problem solving, and relate how their activities and investigations compared to the work of real scientists.

Inquiry was also highlighted through afternoon activities. These activities were designed to enhance the teacher's knowledge about inquiry in general; the differences between structured-, guided-, and open-inquiry formats; and how to transform cookbook-type activities into an inquiry-based format (Coburn 2004). The teachers engaged in inquiries about pH and the effectiveness of antacid tablets and incorporated the concepts of mass, distance, and balance from the morning physics-content sessions into other inquiries with tops and center of gravity that would be appropriate for use in their own classrooms. A chromatography inquiry was performed that modeled inquiry wheels (Pierce 2001), a technique to help students frame potential inquiry questions. After the completion of inquiry activities, explicit attention was drawn to the elements of the NOS present and connections between inquiry and the NOS through an extensive discussion and debriefing session.

As a culminating activity to the summer workshop, teachers worked in collaborative grade-level groups to develop unit plans that incorporated the NOS, inquiry, and the national and state standards. These units were shared with other participants as presentations on the final workshop day and distributed electronically for classroom use.

Method

The study adopted an interpretive stance (Bogdan and Biklen 2003) and focused on the meanings that participants ascribed to the target aspects of the NOS at the beginning and conclusion of the 2-week, all-day, intensive summer workshop. The study aimed to assess how an inquiry-based physics-content course, coupled with an explicit–reflective pedagogy approach, influenced experienced elementary teachers' views of the nature of science and scientific inquiry.

The researchers consisted of one university professor, who served as the project director, and two doctoral graduate assistants, who were project assistants. All researchers served the dual roles of designing and providing professional development for the program, as well as conducting research on the effectiveness of the program.

Procedures and Data Collection

All participants' conceptions of the target aspects of the NOS were assessed pre- and postworkshop using the Views of Nature of Science Elementary School Version 2 (VNOS-D2; Lederman and Khishfe 2002). Participants' views of inquiry were assessed pre- and postworkshop through the Views of Scientific Inquiry-Elementary School Version instrument (VOSI-E; Lederman and Ko 2004). This VNOS-D2, which was designed to be used with elementary audiences, is a modified version of the VNOS-C (Lederman et al. 2002). The survey provides open-ended questions that target the different aspects of the nature of science through examples, including dinosaurs and weather, that are interesting to younger children. Seven teachers, or approximately 30% of the workshop participants, were selected for interviews prior to the workshop and at the conclusion of the workshop. The interviews took place after the teachers had completed the surveys and allowed them to elaborate on their responses, such as providing more examples or clarifying their use of ambiguous terminology, as recommended by Lederman and O'Malley (1990). These interviews also served to and validate our interpretation of teachers' written responses by permitting the researchers to triangulate written responses with interview data. These interviews were audiotaped and transcribed for later analysis.

Videotapes were made of daily physics-content and pedagogy sessions of the workshop. They were viewed at the end of the workshop and were used to ensure that explicit–reflective NOS instruction took place and that nature of science connections were made to the morning physics-content sessions. These videotapes also included data collected from the predetermined checkout sessions in which the teachers' content ideas were questioned and probed for deeper understanding by workshop facilitators.

Data Analysis

Each researcher independently analyzed interview transcripts and questionnaires. Using a matrix where each researcher organized evidence of participants' responses according to each targeted aspect, preinstruction interview transcripts and corresponding VNOS-D2 and VOSI-E questionnaires were separately analyzed to generate profiles of each participant's NOS and inquiry views. The independently generated profiles were then compared to ensure the validity of the questionnaire. This analysis indicated that the researcher's interpretations of participants' NOS and inquiry views as elucidated in the questionnaire were congruent to those expressed by participants during individual interviews. This congruency allowed the researchers to proceed with data analysis. The same process was followed for the postinstruction interviews and questionnaires. For each administration, after this initial round of analysis, patterns and categories were sought in the generated summaries for all participants**.** Researchers went through each set of responses case-by-case and compared evidence (quotes and interview responses) that they had categorized by NOS aspects. Discrepancies in coding led to researchers' discussions, which resolved any conflicts in interpretations by further consultation with the data or through consensus. The categories of participants' understandings of the NOS and inquiry were checked against confirmatory or otherwise contradictory evidence in the data and were modified accordingly. After checking all the available data, the participants' responses were rated for each of the aspects of the nature of science. "No understanding" was assigned when a participant provided answers that showed a lack of understanding (e.g., when mentioning the steps of *the* scientific method). An "emerging understanding" was coded when a participant showed some understanding of a concept, but then also showed persistent misconceptions (e.g., when a participant talked about how scientists collect evidence to form conclusions, but also indicated that with enough evidence theory would become law). An "informed view" was assigned when an answer was provided that showed more complete understanding, and there were no contradictory answers present in instrument responses or other data sources (i.e., workshop notes), such as when a teacher indicated that scientific ideas could change with the collection of new data or reinterpretation of existing data. Several rounds of coding, confirmation, and modification were conducted to satisfactorily reduce and organize the data. These classifications allowed comparison between the two groups after the second administration. Pre- and postprofiles were compared to assess changes in participants' views of the target NOS aspects and views of scientific inquiry.

The researchers viewed the videotapes of institute activities, searching for instances of explicit–reflective NOS instruction in the context of physics inquiries. Notes were made of interactions between facilitators and participants to document NOS instruction. Patterns were sought in the notes to trace progress or changes in participant views of the NOS and the views of scientific inquiry as a result of workshop participation.

Results

In this section, we describe the pre-and postinstruction NOS and inquiry views of the teachers. Representative quotes will be used to illustrate conceptions. All teacher names are pseudonyms.

Preinstruction NOS and Inquiry Views

From the preworkshop surveys and interviews, it was apparent that the elementary teachers in the study held strong misconceptions about the nature of science. The teachers believed many myths about the nature of science, as described by McComas (1996). Some of these misconceptions arose from scientific terms used freely in an everyday and unscientific manner, such as "the science of language arts"; "theories arise from what was experienced in life"; and "educated guess," indicating a conflicting definition between the terms of prediction and hypothesis. In the further exploration of these initial ideas, it was found that the concepts of the nature of science surfaced at various degrees, but at times the correct terminology was absent (observation and inference) or the concept was confused by another term (e.g., tentativeness equated with a lack of confidence) or theory and law. This confusion was evidenced by the following quote:

> I think it was scientific in the aspect that she took something that she observed, created a theory from that, observed it a little bit more to see the fit in her question, and then came up with her conclusion. (Laura, preworkshop interview)

A strong belief in the scientific method was evident at the beginning of the workshop. Most teachers felt the scientific method was important to teach and saw science operating in a "very logical and step-by-step fashion." As one teacher stated, "I thought the scientific method was THE way to do science." Another teacher, who had participated in a science professional development program the previous year, felt it had really changed her view of the scientific method. She shared, "We began to look at that scientific method, wait a minute, and it is not a cut-and-dry sequential-type thing. I think we, as teachers, do a disservice to teaching kids that" (Janet, preworkshop interview). Another teacher compared step-by-step tasks when she said, "Even me, just following a recipe; I feel like I am a scientist" (Laura, preworkshop interview). We believed that we needed to dispel the myth of the scientific method so teachers could focus on science as inquiry and, thus, would be better able to conceptualize NOS aspects.

Social and Cultural Context and Subjectivity

Notions about subjectivity were not always in line with the views recommended by national reforms. For example, one of the teachers stated:

> Scientists do have to kind of–they do not have all of the answers, except for one—then they kind of use their imagination to fit things in. It would be more reasonable imagination, not straight out-of—this-world creativity, but they would have to think…like when we talk about the dinosaurs and finding bone structure, but not actual physical flesh and hair and teeth and all that. They have to use a little imagination to help develop what they would look like. (Amy, preworkshop interview)

Participant responses demonstrated that they believed subjectivity to be different views centered on values, and they explained tentativeness of science by changes in cultural thinking. The participants did not connect the empirical- or evidence-based nature of science to these terms. For example, teachers used many traditional references to the scientific method and how scientists do their work. One teacher explained:

> Hypotheses are educated guesses, basically…I think you need to guess with some common sense behind it and some prior knowledge behind it. I mean, you are going to make a better guess instead of just guessing to guess. And that is what I was trying to teach my students. Don't just guess because you have to guess. But guess with the knowledge that you have and what you see and all the other components to it. (Laura, preworkshop interview)

This participant also saw subjectivity as a form of guessing. When she was asked about why scientists come with different ideas about dinosaur extinction, she responded:

> Because we are all human; we all think differently. My opinion of this class could be different from another person's opinion of the class. It's all about what your own background knowledge is, and there was no one living at that time. So there were no humans around when the dinosaurs were there, so you just have to make you best guess. And everyone guesses differently. (Laura, preworkshop interview)

Four teachers indicated that, if scientists had a complete set of data, they would all agree on the meaning of the data, leaving no room for the influence of a scientist's background or culture on their interpretation of the data. Three others indicated that scientists do think differently about data because of their different belief systems and religions. One teacher simply stated that "science is not perfect"; so, therefore, we could never say that all scientists would agree about the meaning of a data set. One teacher said that, regardless of whether or not scientists all have the same data set, they only focus on the part of the data set that supports their own ideas. Three other teachers held a better view of the role of society, culture, and background knowledge on scientists' interpretations of data by stating that "scientists interpret data through their own background knowledge and view of the world."

Empirical NOS

Prior to instruction, 12 of the teachers simply stated that science was "the study of everything," recognizing that science did seek to explore, but did not indicate the necessity of empirical evidence in those explorations. Three other teachers indicated that science was "problem solving," but did not distinguish scientific problem solving from other kinds of problem solving. One teacher commented:

> Because to me, I think everything is science. I don't see how you can—well, you can't. You can't get through a whole day without solving a problem or

> sitting there and wondering about something; and, to me, you can do that in every single discipline. (Janet, preworkshop interview)

Two other teachers maintained that science "was a study of the world and the environment," again, not noting the need for empirical investigation.

Tentative NOS

Prior to instruction, seven of the eight teachers who indicated science could change held an adequate view of the tentative nature of science. These teachers agreed that the collection of new data could cause scientists to change their claims. In one interview a kindergarten teacher stated:

> Science is change. If you look at it, nothing on this earth ever stays stagnant. In fact, trying to keep something stagnant in its own form is a type of change. In fact to me, if it's a person, and they state that they are a scientist and they are not willing to admit there is a change—they are really not a scientist, they are just an opinionated person. (Mary, preworkshop interview)

However, none of the teachers indicated that they believed a reinterpretation of the same data could influence scientists to change their ideas. The other teacher who indicated that science could change believed that science might change because of advances in technology. Another teacher simply indicated that the scientific method was important in the creation of scientific knowledge, not responding to whether scientific claims may change. One participant indicated that changes in data occurred because of the individual's methods of doing science: "Each scientist brings his own personal perspectives, his own ways of collecting data, asking his own questions, making his own classifications, doing his own experiments; information they have gathered through their own research" (Kayla, preworkshop interview).

Distinction Between Observation and Inference

Prior to participation in the workshop, nine teachers indicated that scientists made scientific claims by searching for patterns and trends in data. However, these teachers did not describe how the data were gathered. Two teachers indicated that scientists make scientific claims through the scientific method. Three others stated that scientists see the evidence and, therefore, understand the idea directly from seeing it—there is no room for interpretation. In interviews, when asked about how scientists know how dinosaurs looked, one teacher talked about how scientists guess, perhaps building on an older definition of hypothesis:

> They don't know for sure. I think that a lot of them have guessed to figure it out. I think they look at our animals that we have now, and they try to figure out if they had similar characteristics. (Judy, preworkshop interview)

Role of Imagination and Creativity

Prior to participation in the workshop, six teachers recognized that scientists use imagination and creativity in all parts of an investigation, including the design of the investigation and interpretation of the resulting data. One kindergarten teacher felt it was important to get ideas started:

> If they didn't use their imagination to begin their search, they would have no beginning place. You have to imagine what you are looking for, knowing it's going to change; but you have to have an imagination to get that theory to start. (Mary, preworkshop interview)

The gifted and talented teacher in particular was adamant about how imagination allows people like Hawking or Einstein to make leaps in their knowledge. She summarized her ideas:

> I think imagination is pulling something that could have been in one part of your brain and putting it with some other evidence that you have looked at all the time. All of a sudden, it takes another level of understanding for you. (Janet, preworkshop interview).

Three others stated that scientists only used imagination and creativity in designing the study, but they had to "report the data found" if their results were to be accurate. They did not recognize the role of creativity in data interpretation. Three others stated that scientists could not be creative or imaginative in designing an investigation because they needed to use a scientific method. Rather, they needed to be creative in interpreting the data found through the method. One teacher noted that scientists had to be creative to be able to "look at all the possibilities," and one other recognized the role of creativity and imagination in helping scientists interpret missing data, such as not finding a complete dinosaur skeleton, but still imagining and creating a full organism from the bones that actually were found. For one teacher in particular, creativity was part of other subject areas, just not science:

> Language arts is more like writing creatively. I feel like science is very concrete. This is happening because of this and this is going to happen because of this. Or we are going to make this out of that. It has to have an exact answer. (Amy, preworkshop interview)

Post Instruction NOS Views

Through the explicit activities involving the targeted NOS aspects and the *Physics by Inquiry* curriculum, improvement was shown in teachers' conceptions of NOS aspects. Change occurred in their definition of science and how science operates as they began to incorporate the ideas of the NOS in their definitions of science. Teachers began to make connections between the morning and the afternoon sessions; as stated by one teacher, "The afternoon NOS instruction helped us see the big picture….In the morning, we were applying it [the NOS ideas]."

For all participants, their vocabulary of the targeted NOS concepts improved, as well as the frequency of their use of these terms, although some ideas were still under development at the workshop's conclusion. Teachers used some terms because they were perceived as the correct answer or "the key terms of the day." However, images of the linear step-by-step fashion of scientific work were being replaced by views of science as a creative endeavor based on evidence. One teacher combined these two ideas in her response when she said:

> I was just thinking back to my new point of view after having done all the inquiry projects, just thinking about the "explore" verbs. You know observe, manipulate, and infer, and I don't know what I wrote before. Before, I was probably thinking observe, hypothesis, test—you know the cycle. (Latisha, postworkshop interview)

Teachers began to see science as more inquiry based; and by doing the inquiries, they could see "how I could put it to work in my classroom." The teachers noticed that the scientific method was not used in the morning activities to learn the physics content, and the questioning techniques used by the facilitators helped them to acquire the new content knowledge in a deeper fashion. These activities downplayed the notion of the only way to do science was through the scientific method. A realization started to emerge that science could be done in multiple ways, although some participants were not able to recognize these alternative forms, such as engaging in science by simply observing and comparing. The teachers may not have recognized how what they were doing in the physics curriculum was different from the scientific method without the facilitators explicitly orchestrating conversations regarding the distinctions. As the workshop progressed, discussions about NOS activities that could be completed with elementary students became more vocabulary laden, with teachers attempting to apply new NOS terms. If a teacher had an incomplete view of one of the aspects, as shown by their workshop comments, the idea was clarified with another example and often addressed on the next workshop day as well. At the end of the workshop, the researchers debriefed participants about areas where they seemed unclear about NOS concepts and planned to provide additional learning opportunities through the school year.

Comments made by the teachers show growth in their understandings of the other various aspects of the nature of science. As described by one teacher:

> Science is more inquiry, and not all things are as exact as they are in [other areas]....Like in language arts, this verb has to go after this word, and history has been researched and stuff. Science seems to change more in what I have seen, especially what we have been doing. (Lindsay, postworkshop interview)

As indicated by the above comment, many positive strides were made by teachers. Of course, the amount of growth varied from teacher to teacher. Some teachers made strong connections between the morning inquiry curriculum, which focused on content and the work of scientists, and the afternoon explicit NOS activities. Their conceptions about the role of evidence, tentativeness, and creativity grew as a result of making this connection. However, not all teachers adequately bridged the relationship between the two sessions. Comments regarding definitions of science still were present at the end of the workshop. Sam, during the postworkshop interview said, “Science is everything. Science is more fun. Students enjoy it more when compared to other subjects the teachers teach.” During the postworkshop survey, Mary said, “Science is interwoven throughout all the subjects…like the science used to create a letter—the science of language arts.”

Empirical NOS

The importance of reliance on evidence became apparent to teachers. As summarized by the teachers, “By doing the physics in the morning, you cannot say you are simply going to do that. You have to know why [based on evidence you gathered]” (Janet, class discussion). One of the survey questions asked the teachers if someone made observations in nature, would it be an experiment. After the workshop, teacher answers talked much more about the evidence. One teacher said, “I would have to do more than just observe. I would have to document data on a number of different birds’ foods in order for it to be an experiment. I would have to isolate variables” (Latisha, postworkshop interview).

Following their participation in the summer workshop, six teachers identified science as determining “the way things work.” Three others described science as “encompassing all the nature of science aspects”—certainly not an intended outcome of the workshop. Three others stated that science was a way of problem solving, and two teachers believed that scientists used observations to make inferences about the world.

Tentative NOS

After the workshop, all teachers agreed that scientific claims could change. The teachers indicated the general idea that “science is not absolute.” Of those, 10 believed that scientific claims could change with new evidence and data. Growth in this area was assisted by the inquiry connection; the teachers saw their ideas about physics change as they gathered more evidence as their inquiries progressed. None of the teachers indicated they understood that a reinterpretation of existing evidence could cause a change in scientific ideas. One interview response showed a sophisticated answer, but still some areas of concern with terminology like “proven” present.

> Their current ideas will most likely be disproven when new information becomes available. Ten teachers stated that scientists would use data to make predictions and to imagine the meanings of evidence. So that will have to be adapted, based on new findings. (Latisha, postworkshop interview)

Distinction Between Observation and Inference

Regarding the distinction between observation and inference, after the workshop, 16 of the teachers demonstrated an improved view. In addition to noting patterns and trends, 10 teachers explicated ideas that showed their views that scientists would use data to make predictions and to imagine the meanings of evidence. The teachers were beginning to see observation as a viable method of doing science. When asked if a scientist making observations was doing scientific work, Sam replied, “Yes, making observations and making conclusions based on the information. Observations and inferences are based on evidence. Creating answers to her questions.” Kayla responded, “Yes, she was making observations, inferences, classifying, interpreting, and collecting data.”

Three simply stated that “scientists use observations and inferences to make claims.” Some teachers were still having difficulties seeing observation as a method of science. Betty stated, “I think she was doing an experiment-by making observations, but they are not scientific in nature. They are just observations. They are not backed up by evidence or theories.”

Other teachers showed similar difficulties when they said: “[The scientist] would have to do more than just observe to draw this conclusion” (Latisha). “Hard to tell because we don’t know of the procedure she used to gather evidence” (Pam). Another teacher had a very confined view of what could be classified as an experiment, “Now she needs to set up a formal experiment where the data can be collected in such a way that others or she can replicate the process” (Janet). This view is especially interesting because this teacher engages in long-term local environmental observations with her students.

Social and Cultural Influence and Subjectivity

During a debriefing of the workshop, teachers discussed that they became more aware of their own subjectivity and tentativeness in connection with scientific claims through doing investigations in the morning physics curriculum. Through the checkout process, they said they learned to question their own assumptions formed from their previous experiences. Following the workshop 12 teachers agreed that society and culture influence the interpretation of evidence. Two of those 12 added the idea that background knowledge of the scientist also influences interpretation of evidence. As captured by one participant, “Scientists use empirical evidence using fossilized bones. They are not certain about what dinosaurs are like, but use observations and inference that are influenced by their personal and cultural perspectives” (Sam). “Background experience explains how scientists can have the same information, but develop different conclusions. Scientists use background knowledge, past experiences, what they have learned from others” (Lindsay). Three others retained the view that, if scientists had a complete data set, they would all agree on the interpretation of data. One teacher suggested that culture changes from science, but did not acknowledge that science is influenced by culture.

Role of Imagination and Creativity

Eight teachers stated that scientists used their creativity and imagination to design studies and interpret evidence and to create new scientific ideas, showing growth from the initial ideas that creativity is only used in the beginning of an investigation. Four others held the view that scientists use imagination and creativity to develop explanations and interpret data. As shared by one of the teachers, “The scientists create how they are going to do their explorations and experiments, look at data, and come up with different ways or designs to use as they do their research” (Kayla, postworkshop survey). Two teachers stated that scientists use their imaginations and creativity to interpret evidence, despite having missing data. One of those teachers, who expanded her answer from her preworkshop response, stated:

> They have to imagine what could have been to explain what is.…If there are missing parts of the data, when you gather data and you get to a point where there are no more data, then you have to imagine or predict [you ask] “What are the possibilities?” (Latisha, postworkshop interview)

One stated that scientists use their imaginations and creativity to make sense of the world. This change in her thinking is captured in her comments after the summer session:

> I did not think they [the scientists] use their creativity and imagination before; science was very logical and step-by-step. Now the more we know, we realize that they have to be creative to pull all these separate facts into one understandable connection. They have to be able to draw from their culture and experiences and, using their creativity, create a picture of what is happening. (Laurie, postworkshop interview)

Summary

To better understand how all participant ideas changed, Table 2 summarizes the participants’ changes in ideas. As discussed above, it is noticeable that, while the majority of the participants changed their ideas about the nature of science, for many, these changes are interspersed with persistent misconceptions about the nature of science, including a model of the scientific method, science being no different than other disciplines, or creativity and imagination being isolated to a single part of the scientific endeavor. The difference between how the participants processed information from the beginning to the end of the workshop was evident. Participants were more willing to use more vocabulary and also did not take instruction at face value. Those who made a connection between the morning physics sessions and afternoon NOS sessions found that they could not simply base their ideas on a hunch or what they thought was true; the need for evidence was reinforced. Videos of the workshop showed that participants struggled and challenged themselves throughout the workshop to incorporate new ideas and challenge their previously held beliefs. The teachers began to change their misconceptions about using the scientific method and about how science operated in general. The teachers noticed that they did not use the scientific method in their inquiries, so they were beginning to see the flaws in their conceptions; but many were still not ready to exchange their old beliefs for new ones.

The research and professional development team was able to use these results in planning future workshops and activities to assist participants in overcoming

Table 2 Participant Ideas Before and After Summer Workshop

Preworkshop	Postworkshop
What is science?	
12 Science is the study of everything	1 Science is everything
3 Science is problem solving	2 Science is not scientific method
2 Science is the study of world and environment	3 Science is problem solving
	6 Science is how things work
	2 Science is observation and Inference
	3 The participants listed the nature of science aspects
How is science different from other subjects?	
3 Science is more hands-on than other subjects	2 Science is hands-on and more fun than other subjects
1 In science, there is no one right answer	3 Science is not different from other subjects because it is problem solving
7 Science is in everything, its integrated throughout	2 In science, you can revise ideas and they can change
3 There is no difference between science and other subjects	3 Science is embedded in other subjects
1 Differences between science and other subjects need to be researched	4 Science is in everything or it is not different from other subjects
	1 Science has nature of science, and other subjects do not
	2 In science you investigate—it is a process
Is science tentative?	
8 Science can change	7 Science can change
1 The scientific method is important	10 Science will change with new info/data/inferences gathered
1 Science is a series of educated guesses	
2 As technology changes, so does science	
7 Once there is new data, science changes	
How do scientists use observation and inference? (asked in context of understanding what happened to dinosaurs)	
2 They use the scientific method	10 Scientists predict or imagine from evidence
3 Scientists saw images or looked at remains	3 Scientists use observations and inferences
9 Scientists look at patterns, trends, or data	1 With more data they'd have better ideas
Social and cultural–subjective aspects of the nature of science: Why do scientists come up with different ideas when working with the same information?	
3 Different scientists think differently or have belief systems or religion	2 Scientists may be working with an incomplete data set
4 With more evidence. all scientists would agree	2 Society and culture influences a scientist's interpretation
1 Science is not perfect	10 Background knowledge or subjectivity and culture influences scientist ideas
3 Scientists Interpret data based on their background knowledge	1 Culture changes from science

Table 2 continued

Preworkshop	Postworkshop
1 Scientists focus on data that supports their ideas	
Is creativity and imagination used in science? And if so, when?	
6 It is used at all stages—design and interpretation	4 It is used to make explanations/interpret data
3 It is only used for interpretation	2 Scientists use it to interpret missing data
3 It is only used for design of processes	8 Scientists used it to design interpretation and create new ideas
1 It allows a scientist to look at all possibilities	1 It is used to make sense of the world
1 It is used to fill in the data “blanks”	

persistent beliefs. For example, a follow up workshop featured a speaker who discussed different models of scientific methods and information on how scientists in different disciplines approach problems.

Discussion and Implications

Our results have shown that, though teachers were initially reluctant to participate in physics inquiries, they concluded the program by finding it to be a positive experience. Learning physics-content knowledge through inquiry techniques proved a challenge for the teachers. For many, it was the first time the teachers had personally experienced learning science through any inquiry techniques. This experience allowed the teachers to construct their content knowledge; but, at times, the teachers admitted it was frustrating for them because they “just wanted the answers.” The checkouts made them feel uneasy at times; the teachers wanted to be given the correct answers. Constructing knowledge for themselves was more difficult. The teachers began to fully realize the difficulties of learning by inquiry techniques and the frustration that might be felt by their students when using inquiry. However, by the conclusion of the workshop, the teachers began to feel the success of learning conceptually and could see how this may translate to their own students’ learning. For example, one of the kindergarten teachers stated, “I have never learned physics before. I am so excited! I didn’t know I could actually do it!” Teachers noted that they “felt a sense of freedom” in their science teaching. As described by one teacher:

> I have been told and I believe everything I was told. I wanted answers, and I wanted the kids to have answers. I wanted to provide the kids answers if they could not figure it out for themselves. And how it is like, whatever.…It [use of inquiry and NOS] is going to make me a lot more relaxed when I am teaching science. I was scared to death about teaching science; it was all that was left when I started teaching sixth grade. So I was quite intimidated by my first class. (Laura, postworkshop interview)

Our results support prior research that an improved understanding of the NOS can be gained by allowing teachers to experience science through inquiry that is connected to an explicit–reflective NOS approach (e.g., Schwartz et al. 2004). By allowing teachers to experience their content learning through inquiry, both of physics and the nature of science, some teachers developed a deeper understanding of the nature of science in practice. Our results support the notion that experiencing scientific inquiry as the work of a scientist may not be enough to fully understand the NOS (Schwartz et al.). While some teachers did make the connection between morning and afternoon activities, not all participants were able to see a meshing between the content inquiry and the NOS sessions. Part of this may be accounted for by the teaching practices of the professional development staff. Upon review of the video tapes of explicit NOS teaching practices, it was discovered that, at times, connections were not as strong as they needed to be. The targeted nature of science aspects are not easily visible just through practice alone; and without these explicit references, teachers are not able to make these connections. Those participants who did bridge the two sessions showed substantial gains and deeper understanding of the NOS, as shown by the overall consistency of their final responses in comparison to beginning responses. For example, in her postinterview, Janet, who had a substantially improved view of the NOS aspects, talked about activities where she saw how she could use NOS aspects as a unifying concept with her established lessons. Those who did not bridge the two sessions still had misconceptions present in their final responses; however, the researchers did not observe anyone's responses that were completely unchanged between pre- and postworkshop administrations. For example, Christine, who had an improved NOS view, but to a lesser degree, had never taught science; but at the end of the workshop, she saw the NOS as way to incorporate some science instruction into her literacy activities. All participants showed some level of improvement in conceptualization of NOS aspects. Two weeks is a very short time for a participant to change ideas and habits they may have held for decades (Akerson et al. 2006; Khishfe et al. 2002; Ogunniyi 1982). The research and professional development team did not have the expectation that all of the participants would have completely grasped all of the target aspects. However, the teachers who showed persistent misconceptions, such as a single scientific method and misunderstandings about theory and law, directed future interventions and reteaching of important concepts. These documented misconceptions were unchanged at the end of the first summer workshop, alerting us that we needed to provide further interventions to support the teachers in replacing old ideas with new images that are aligned closer to those in the reform documents. Explicit–reflective instruction is needed to connect the real-life practices of scientists and the NOS. After each activity or laboratory session, the aspects of the nature of science need to be explicitly discussed to achieve a deeper understanding of the true nature of the work of scientists. Having teachers complete inquiry activities is not enough to change a teacher's views about the NOS. Direct and clear connections need to be made after all types of activities, especially in the case of participating in scientific inquiry, for a deeper understanding of the NOS to occur.

We believe that teachers need professional development programs to conceptualize the inquiry strategies and the true nature of scientific endeavors being advocated and to aid in translating these new ideas to classroom practice. Our research study adds to the current body of knowledge about how best to structure this professional development by showing the results of a guided inquiry paired with explicit–reflective NOS instruction model. The elementary teachers who participated in the 2-week workshop experienced gains in their knowledge of the nature of science, the first crucial step needed for successful classroom implementation. Many of the teachers held misconceptions about the NOS; without proper intervention, these erroneous ideas perpetuate and are passed on to a new generation of students. Promising strides were made in the teachers' beliefs about the NOS through the explicit reflection in the afternoon sessions that connected with the scientific inquiry in morning sessions. The inquiry practices and connections assisted the teachers in realizing how the aspects of the NOS intertwine with inquiry and helped some to take on a more developed notion of the NOS. We note that the all-day, 2-week workshop was not enough for all participants to develop accurate notions of the NOS. Other studies have found that sustained intervention and individualized support are necessary for teachers to formalize their NOS understandings and to translate them into classroom practice (Akerson and Abd-El-Khalick 2003; Akerson and Hanuscin 2003, 2005). Follow-up interventions are needed to support the change-in-views process started in the workshop and to help the teachers incorporate the NOS into their classroom practice. This follow-up support will include monthly all-day workshops at various school sites, as well as individualized in-class support by project staff.

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