Chapter 12
Impact of a Nature of Science and Science Education Course on Teachers' Nature of Science Classroom Practices

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Introduction

Understanding the nature of science (NOS)—what science is and how it works, the epistemological and ontological foundations of science, how scientists function as a social group, and how society impacts and reacts to science (Clough, 2006)—has been a science education goal for well over a century (Lederman, 1992) and is prominent in contemporary science education reform documents (AAAS, 1989, 1993; McComas & Olson, 1998; NRC, 1996). Many arguments have been put forward for accurately teaching and understanding the NOS (Matthews, 1994; McComas, Clough, & Almazroa, 1998; Robinson, 1968). However, despite the overwhelming agreement regarding the importance of accurately and effectively teaching the NOS, much remains to be done in moving the vision to a reality in elementary through postsecondary science education.

That many science teachers possess inaccurate or simplistic views of the NOS (Abd-El-Khalick & Lederman, 2000; Carey & Strauss, 1970; Lederman, 1992; Miller, 1963, Schmidt, 1967) and are generally unaware of the social and cultural construction of scientific thought (Brush, 1989) is well established. Over 40 years ago Elkana (1970) stated that science teachers' views concerning the NOS trailed contemporary philosophical views by more than two decades. Two decades ago, DeBoer (1991) reviewed the history of science education and noted that an outdated view of the philosophy of science continued to impact classroom practice and permeate popular science curriculum materials—a situation that persists today. Science textbooks, common cookbook laboratory activities, and most audiovisual materials ignore or downplay human influences in research, sanitize the work that eventually resulted in accepted scientific knowledge, and portray science as a rhetoric of conclusions (Cawthron & Rowell, 1978; Clough, 2011; Jacoby & Spargo, 1989; Leite, 2002; Munby, 1976; Duschl, 1990; Rudge, 2000).

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Given the state of science teachers' understanding of the NOS, not surprisingly, studies also document students' and the general public's misconceptions regarding scientists, how science works, and the nature of scientific knowledge (Clough, 1995; Durant, Evans, & Thomas, 1989; Millar & Wynne, 1988; Miller, 1983, 1987; NAEP, 1989; National Science Board, 2002; Rowell & Cawthron, 1982; Rubba, Horner, & Smith, 1981; Ryan & Aikenhead, 1992; Ziman, 1991). The NOS misconceptions held by science teachers, their students, and the general public and promoted in science textbooks coalesce to form a powerful self-supporting network that continues the vicious cycle generation after generation.

These significant misunderstandings regarding the NOS interfere in deeply understanding science content and they impact students' attitudes toward science and science classes. The following student's frustration illustrates how misunderstanding regarding the NOS may affect interest in and understanding of science content.

> What is this game that scientists play? They tell me that if I give something a push it will just keep on going forever or until something pushes it back to me. Anybody can see that isn't true. If you don't keep pushing, things stop. Then they say it would be true if the world were without friction, but it isn't, and if there weren't any friction how could I push it in the first place? It seems like they just change the rules all the time. (Rowe & Holland, 1990, p. 87)

Moreover, Tobias (1990) interviewed a number of successful postsecondary science students and reported that they became disenchanted with science classes and chose different majors, in part, because science courses ignored the historical, philosophical, and sociological foundations of science. Students appear to value learning about the NOS when it is taught in a developmentally appropriate and engaging manner (Meyling, 1997), and Clough, Herman, and Smith (2010) report that postsecondary students' interest in science and science careers increased after having read several historical short stories addressing how scientific knowledge was developed and came to be accepted.

Nevertheless, despite a wide variety of efforts aimed at encouraging teachers to devote explicit attention to NOS instruction, results have, for the most part, been disappointing. Teachers generally appear unconvinced of the need to emphasize the NOS as a cognitive objective (Abd-El-Khalick, Bell, & Lederman, 1998; Lederman, 1998), and see NOS instruction as detracting from their primary mission of teaching science content. Lakin and Wellington (1994) point out that NOS instruction appears to be contrary to "expectations held of science and science teaching in schools, not only by teachers and pupils but also those perceived as being held by parents and society" (p. 186). Too often science teachers simply do not consider the nature of science an important component of science education (Bell, Lederman, & Abd-El-Khalick, 1997; King, 1991). For instance, Bell et al. (1997) followed several preservice teachers through their student teaching experience to determine how extensively they implemented nature of science instruction. Despite significant attention placed on the nature of science in their preservice program, most of these teachers did not show significant explicit attention to teaching the nature of science, and one participant in the study made the following statement: "I don't plan to teach

Table 12.1 Course objectives

1. Develop and articulate a well-informed and fervent rationale for accurately portraying the nature of science in everyday instruction.
2. Develop a set of developmentally appropriate student actions consistent with an understanding of the nature of science.
3. Describe explicit nature of science content, materials, and activities in decontextualized settings (i.e., the focus is exclusively on the nature of science and is divorced from science content instruction).
4. Describe explicit nature of science content, materials, and activities in contextualized settings (e.g., linking the nature of science with science content using typical activities, videos, reading assignments, and authentic historical or contemporary science anecdotes).
5. Describe teacher behaviors and strategies for explicitly drawing the attention of students to and having them reflect on the nature of science.
6. Accurately assess nature of science teaching (and lack of it) in a science lesson.
7. Modify a 2–4 week lesson plan so that it more accurately, explicitly, and consistently addresses the nature of science both decontextually and contextually.

the nature of science. . . . I don't think it is something that I would spend a great deal of time on."

These challenges call for different and more extensive approaches to promoting accurate and effective NOS instruction among science teachers. To this end, the first author developed and taught a course for preservice and in-service teachers devoted exclusively to accurately and effectively teaching the NOS to secondary school students. The two-credit semester length course was directed at achieving the objectives found in Table 12.1.

Students in the course experienced practical science activities in settings where the focus is exclusively on the nature of science (decontextualized NOS instruction), as well as in settings where the focus is primarily on science content (contextualized NOS instruction). The major theme of the course was that significant attention to the nature of science could be achieved with only minor modifications to existing curricula and the teacher's role while implementing those curricula. Toward those ends, students in the class modified science curriculum materials to accurately portray nature of science concepts in both decontextualized and contextualized ways, and addressed teacher behaviors that explicitly draw the attention of students to the nature of science. See Clough (1997, 2006) for a more thorough description of the kinds of NOS activities and instructional approaches modeled and promoted in the course.

The study reported here followed students who completed the NOS course at a large Midwestern research-extensive university to determine their NOS implementation practices in the secondary science courses they later taught. In addition, we sought to determine the connection between their NOS instructional practices and their performance in the course, their rationale for teaching NOS, and the institutional constraints they face. The research questions were as follows:

1. To what extent do study participants effectively teach the nature of science in ways consistent with those promoted in the NOS course?

2. How do study participants' NOS implementation compare to their
   (a) understanding of the nature of science at the completion of the course?
   (b) rationale for teaching the nature of science?
   (c) institutional constraints?

Methodology

Course Context and Participants

All study participants took the NOS course as an elective during the summer prior to the study and at that time were either completing their initial teaching license, a masters degree in science education, or were completing university credits for further professional development and state teaching license renewal. All course participants had previously completed two two-credit courses that addressed the history and nature of science content, and all were pursuing or held secondary science teaching licenses. Both of those prior courses focused exclusively on issues in the history, philosophy, and sociology of science and their relevance to science education, but with no emphasis on pedagogical practices to effectively convey the history and nature of science to students. The first author who created the elective NOS course described above did not teach the two prior courses but was intimately familiar with them, had previously completed more than 20 credits of course work in the history, philosophy, and nature of science during his science education doctoral program, and had 6 years of postdoctoral experience effectively teaching the NOS to high school students prior to designing the course.

Study Procedures and Instrumentation

During the first class session, course participants ($n = 13$) completed informed consent forms agreeing to participate in the study. Immediately afterward, each participant completed 27 VOSTS items (Aikenhead, Ryan, & Fleming, 1989; Aikenhead & Ryan, 1992) that assessed their NOS understanding, and a writing task that asked what they thought were reasons for accurately and effectively teaching the NOS (Table 12.2). At the end of the course, participants submitted a 10–20-day unit plan that they had revised to incorporate both decontextualized and contextualized NOS instruction. Course participants then once again completed the VOSTS and the writing task.

While all 13 course participants agreed to take part in this portion of the study, school district approval to observe classrooms was denied for four teachers; a fifth participant chose to work in a science laboratory; a sixth participant taught in an inaccessible location; and a seventh participant experienced significant difficulty during the semester unrelated to the study and chose to leave the study. Information regarding the remaining six teachers that made up this study appears in Table 12.3.

Table 12.2 Writing task for determining study participants' reasons for teaching the NOS

A friendly and interested colleague asks you to write a letter explaining why accurately teaching about the nature of science instruction is important for teachers and students. Below please write the reasons you would provide so that colleagues, administrators, and parents would understand your rationale.

Table 12.3 Study participant information

Participant	Gender	Years teaching	School type
1	M	5	Large suburban
2	F	1	Small rural
3	F	1	Small rural
4	M	1	Small rural
5	M	3	Large urban
6	M	6	Large suburban

During the fall semester after having completed the NOS course, the six study participants were observed teaching on three separate occasions. Each visit was arranged with the teacher in advance. During those visits we examined classroom artifacts (bulletin boards, student work, handouts, and lesson plans), and observed classroom interactions. During these classroom observations we looked for evidence of the following:

1. Interaction between the teacher and students that explicitly addressed NOS ideas, questions teachers asked to draw students' attention to NOS ideas, and student questions about the NOS;
2. Teachers' accurate use of or avoidance of language having NOS implications (e.g., law, theory, prove, truth, how does a particular idea *account* for data rather than the data *tells*, etc.);
3. Decontextualized NOS activities and discussions;
4. Contextualized NOS activities and discussions;
5. Classroom artifacts that sent messages about the NOS.

These practices reflect the objectives of the NOS course that study participants had completed during the previous summer and the central ideas that a prior analysis (Olson & Clough, 2003) had established were clearly emphasized during that course. Field notes were taken by each researcher and compared after the visit.

Teachers' implementation practices on the above criteria were coded low, medium, or high. Low ratings were given when teachers classroom practices and artifacts indicated they implemented decontextualized NOS instruction and had their students reflect on those experiences, but did not create or capitalize on clear opportunities to address the NOS with their students in the context of science content being taught or inquiry activities being conducted. Low implementers might also be observed stating incomplete or somewhat inaccurate NOS ideas at times, and they did not engage students in reflecting on NOS ideas that were present in more contextualized situations.

The medium NOS implementation category was used for teachers who implemented decontextualized NOS instruction and had their students reflect on those experiences, but who also created and capitalized on at least some clear opportunities to address the NOS with their students in the context of science content being taught or inquiry activities students were conducting. However, medium implementers are noticeably less effective than high implementers at drawing their students' attention to and helping them grasp desired NOS ideas.

Teachers in the high implementation category not only employed decontextualized NOS activities and had their students reflect on those experiences, but also often created and capitalized on opportunities to address the NOS with their students in the context of science content being taught or inquiry activities being conducted. Their NOS instruction was explicit, reflective, and ubiquitous in many of their science instruction contexts. These teachers were effective at drawing their students' attention to key NOS ideas in multiple contexts and having them reflect on those NOS ideas.

Following each visit, we conducted semi-structured interviews with each teacher to ascertain (1) their goals and objectives for the lesson; (2) their impression of the lesson; (3) what NOS ideas they have previously taught to their students; (4) how they have conveyed those ideas to their students, and (5) successes and challenges they encounter in their attempts to teach the NOS. After comparing field notes from the all three observations and interviews, the two researchers jointly developed a profile of each teacher. Table 12.4 provides an example of such a profile. These profiles along with more detailed observation notes and artifact analysis were used to determine the NOS implementation patterns of study participants and assign them an overall low, medium, or high implementation category. For instance, Teacher 3's NOS implementation was coded as low. She taught a decontextualized NOS unit at the beginning of the school year and subsequently did not explicitly incorporate NOS instruction in the context of science content or activities, nor did she ask questions or make other instructional moves that would have drawn students' attention to NOS ideas and have students reflect upon them.

The teachers' VOSTS and writing task were analyzed separately by both researchers. We looked for changes in responses on the VOSTS items before and after the course, as well as after a year of teaching. Areas where changes occurred were noted and these shifts were compared to implementation practices and student responses on the questionnaire. The writing task was analyzed to determine how study participants' rationale for teaching the NOS changed with classroom experience and if high implementers had different rationales than low implementers. A coding system developed by Bruxvoort, Olson, Clough, and Vanderlinden (2003) using both open and axial coding was used to generate and then reduce study participants' writing task responses to the categories appearing in Table 12.5.

In late November/early December, students in the six teachers' classes completed a brief voluntary and anonymous questionnaire to determine the kind and frequency

Table 12.4 Sample teacher profile

Teacher 3 teaches tenth grade biology. She says teaching the NOS is very important and she claims to have emphasized it a great deal in her classroom. During our visit, students were very unruly and disrespectful of one another and of the teacher. Class time was spent entirely on issues of science content, with a great deal of student seatwork using their textbooks. Teacher 3 appeared frustrated and had difficulties getting the students on task.
Several opportunities to address the nature of science were missed during the lesson. The portion of the book they were reading contained inaccurate historical examples. Students and the teacher frequently misused the term *theory* and *prove*.
After the lesson, Teacher 3 expressed her frustration with the students and the administration. She said she had students complete some VOSTS items at the beginning of the year, and had done some decontextualized activities such as the tricky tracks and mystery tube activities, but "I haven't had time to address the nature of science since then." When asked why, she said she felt pressure to cover content and her frustration with the students' behavior prevented her from having the desire to expend extra time and effort to include the NOS when they couldn't even handle science content. She also cited coaching responsibilities and family issues as preventing her from spending extra time to prepare for classes. When asked about the administration, she said they do not understand or value the NOS and want the class to cover the science content in the textbook.

Table 12.5 Rationale for teaching the NOS provided by study participants

1.	Increases student interest in science content
2.	Increases student interest in science careers/courses
3.	Increases student appreciation of science
4.	Increases understanding of science content/understanding of what is fundamental content
5.	Teachers teach NOS regardless of intention, so we may as well do it right
6.	Understand science and its relationships to technology and society (e.g., funding)
7.	Develop more informed citizens (voters, jurors)
8.	Students will understand that science is a human enterprise
9.	Students will better understand science processes/how science is done (doing science requires creativity, no algorithmic scientific method exists, etc.)
10.	Shows connection between subjects (history, etc.)
11.	Understand the difference between science, pseudo-science, and religion
12.	I have to; it's in the reform documents (standards, etc.)
13.	Students will find science relevant

of NOS instruction they perceived was addressed during the fall semester. We also asked students to briefly write about their impressions of NOS instruction.

At the end of the school year, a structured interview was conducted with the teachers to determine their perceptions regarding (1) the extent to which they had implemented NOS instruction; (2) what helped or hindered their teaching of the NOS; (3) confidence in their understanding of the NOS content and pedagogy; (4) their goals for students, including their rationale for teaching the NOS; (5) their future plans for NOS instruction; and (6) their feedback regarding the course and what could have been done to better prepare them to teach the NOS. To increase the likelihood that teachers would honestly critique the NOS course and describe their own NOS teaching experiences, all year-ending interviews were conducted and analyzed by the second author, who did not teach the NOS course.

The interviews were conducted by telephone, audiorecorded, and transcribed. Analysis was conducted using Strauss and Corbin's (1998) open and axial coding techniques to elicit patterns of implementation and common themes. Teachers completed the 27 VOSTS items and the writing task one final time.

Findings

Extent and Character of Teachers' NOS Implementation

All six study participants made deliberate efforts to teach the NOS, although they ranged widely in their implementation practices. Four of the six taught the NOS consistently and contextually, both in decontextualized settings and contextualized within science content instruction and inquiry activities. They often asked questions that had students reflect on particular NOS issues relevant in everyday science instruction. Of the remaining two teachers, one often addressed the NOS in a decontextualized manner at the beginning of class, and the other taught a NOS unit in a decontextualized manner at the beginning of the school year. Neither of these two low NOS implementers appeared to purposely teach the NOS outside these very limited contexts. Table 12.6 summarizes each study participant's overall NOS instructional implementation rating.

The four teachers categorized at high levels of implementation had much in common. First, they all taught the nature of science both decontextually (the focus of a NOS lesson or activity was unrelated to science content instruction), as well as contextually (NOS instruction was embedded within science content in a lesson and at times included examination of scientists' work and statements about their work). One of the four high-implementation teachers (Teacher 2) relied solely on activities used during the summer NOS class, but the other three used the class activities and supplemented their units with additional resources they found on their own. All four high implementers used a variety of NOS instructional strategies that included decontextualized puzzle-solving activities (e.g., tube activities, gestalt switches, etc.,), additional readings outside the textbook (such as excerpts

Table 12.6 Participants' NOS implementation levels

Teacher	NOS Implementation
1	High
2	High
3	Low
4	Low
5	High
6	High

from James Watson's "The Double Helix") that provided rich material for addressing important NOS issues, videos such as "Lorenzo's Oil" that were also used to raise NOS issues, explicit class discussions about a number of NOS issues (e.g., to what extent was the structure of DNA created and/or discovered), required student journal writing addressing NOS issues, and assessments that included questions addressing the NOS. These teachers created, recognized, and utilized opportunities within everyday lessons to explicitly raise NOS issues with their students.

The two teachers at low levels of implementation missed significant opportunities to address the NOS. Teacher 4 identified opportunities during a lesson where he could have addressed a NOS idea, but he deliberately chose not to do so, stating that he felt the students had already had a lot of NOS and needed more time and focus on science content. Thus, while this teacher asserted in his written response to the question appearing in Table 12.2 that NOS and science content are equally important, he gave priority to "covering" the biology content and made pedagogical decisions that detracted from accurate and effective NOS instruction. When asked what biology content took such high priority for his students, he referred to content that was included in his own high school biology class. Teacher 4's decision to downplay NOS instruction in favor of covering science content was made even though no mandated curriculum or high-stakes science content exam constrained his decision making. His solution to the problem of teaching the NOS while still "covering" the content was to occasionally set aside approximately 5 min in a class to address a NOS concept via a decontextualized NOS activity. Ironically, teacher 4 did not appear to consider that periodically integrating the NOS in a contextualized fashion would require little or no more time than the decontextualized NOS instruction he was implementing.

Teacher 3 taught a decontextualized NOS unit at the beginning of the school year and did not plan for and incorporate accurate and effective NOS instruction beyond that early effort. Even when opportunities clearly existed to address the NOS in the normal course of teaching science content, this teacher chose not to do so. While expressing a desire to incorporate NOS while teaching content, this teacher was most concerned with classroom management issues and related pressure from the principal which weighed heavily on the teacher's instructional decision making and practices. Our impression was that this teacher was trying to survive the year rather than concentrate on ways to improve NOS practice.

Our overall assessment of teachers' NOS instructional practices matched students' perceptions of NOS instruction occurring in their class. Students in all four teachers' classrooms who administered the student questionnaire (Teachers 2, 4, 5, and 6) wrote responses indicating that their teacher devoted at least some time to teaching the NOS. The first question asked of students was "What kinds of activities or discussions occurred in class that help you understand what science is like and how it works?" Student responses were coded *positive* if they could generate a specific NOS-related course experience. A *neutral* code was assigned if the student made a neutral comment about the course but whether the student was referring to NOS instruction could not be determined. A *negative* code was assigned if students made a negative statement about the course but whether the student was referring

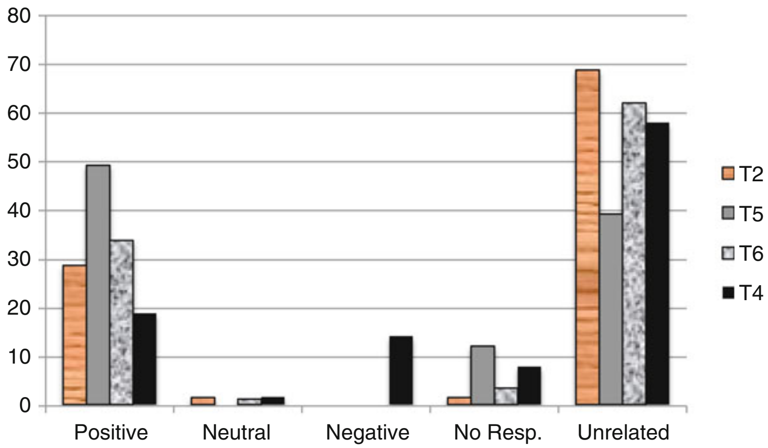

Fig. 12.1 Percentage of student responses that recalled NOS activities or discussions

to NOS instruction could not be determined. A code of *unrelated* was assigned to any response that provided course experiences, but the experience appeared to be designed to teach science content and not the NOS. Many students interpreted the question to mean "What activities helped you learn science content?" and thus provided a list of laboratory experiences that were coded "unrelated." Figure 12.1 provides the percentage of students in each response category for each of the four teachers whose students completed the questionnaire. Students' responses in high NOS implementation teachers' classrooms (Teachers 2, 5, and 6) are represented by the three bars at the left in each category. Students' responses in the low NOS implementation teacher's classroom (Teacher 4) appear to the far right in each category (represented by the dark bars).

Responses appearing under the *positive* category identified specific nature of science concepts their teachers taught (such as the differences between basic and applied science, the lack of a single scientific method, how a scientist's prior knowledge affects observations, etc.,).

At least 18% of the students in all four teachers' classes could identify that they were learning the nature of science, reflecting that even the low-implementation teacher addressed the NOS to some extent. Notable is that the high-implementation teachers had a much greater percentage of students who could recall specific instances in which the nature of science was addressed. The following quotations from students illustrate the kinds of activities in which students were engaged:

> We looked at a lot of pictures where you could see two things in one object such as an old woman or a young lady. Showing us pictures like that showed us how our prior knowledge can affect which one we saw. We did many of those to help us. We filled out a sheet and it had different experiments and basic/applied science on it. We had to number least to greatest on what we would give money to. And we said what percent we would give them. That showed us how basic stuff can turn into applied science and so on. (Teacher 5, student response 1.54)

> We had a lot of discussions on the nature of science and almost every experiment he pointed out that our observations might be based on our prior knowledge. (Teacher 5, student response 1.72)
>
> We had a lot of discussions about how there are no facts in science, only best answers. I didn't know that before. We also had many discussions on different points of view of different scientists. We had lots of discussions on the similarities and differences, also interactions between applied science, basic science, technology, and how prior knowledge affected them. (Teacher 2, student response 2.01)
>
> We did charts and a lot of discussions about prior knowledge and about how science cannot be proved. (Teacher 2, student response 2.16)
>
> One of the big things that I did was a science fair project. It showed me an idea of how scientists conduct research. I know they have to go through lots of research and work and it's not just a single method. (Teacher 6, student response 1.19)

The consistency between students' reports of NOS instruction, teachers' self-reporting, lesson planning artifacts, and our classroom observation together provide compelling support for our categorization of teachers' NOS instructional implementation practices. For example, one teacher claimed he did not spend time on the difference between basic and applied science, and students' responses on the questionnaires, our classroom observations, and our analysis of lesson planning artifacts support this.

Student Perceptions of Their NOS Learning

As part of the questionnaire, students were asked to describe how their views about science and science classes have changed since the beginning of the school year. Responses were coded *positive* if students reported positive changes in their understanding of science or science classes, *neutral* if they made a statement that was related to the question but was neither positive or negative, and *negative* if they responded negatively about science or science classes. *Unrelated* was used when students responded in a way that was unrelated to the question. The percentage of students who responded in each category is provided in Fig. 12.2.

Figure 12.2 illustrates the differences between teachers who implemented NOS at high and low levels. Teacher 4 (in the dark bar on the far right for each category) is a low-implementation teacher. Despite 18% of his students identifying that they were learning NOS concepts in question 1, their overall response to the course was neutral or negative, with most students making comments about unrelated topics and only 8% perceiving positive changes in their views about science and science classes. One student remarked, "They have not changed at all, at the beginning I was going to just get my credits for science and quit and I am still going to do that because our science program needs help" (Teacher 4, student response 1.58). Another said, "Yes, I dislike it a lot more" (Teacher 4, student response 1.59).

The perceptions of students in classes where the NOS was taught at a high level of implementation differed dramatically. Between 65 and 92% of the students in those classes reported positive changes in their views toward science and science classes. One student wrote, "At the beginning of the term I came from prior classes

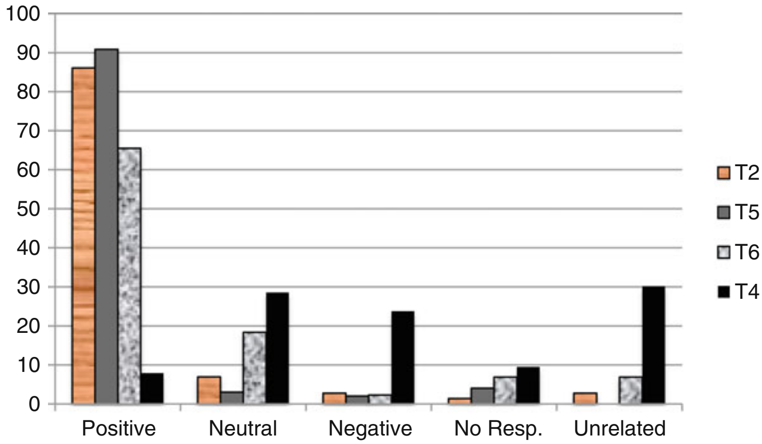

Fig. 12.2 Percentage of student responses about how their views of science and science classes have changed

that only taught us about the scientific method and how it is used for everything in science. Now coming from [Teacher 5] I know that is not true. And never once in any of my other classes had we ever talked about the nature of science. Some things I never even had a view on, now I do." (Teacher 5, student response 1.20)

Students, particularly those in the high NOS implementation classrooms, reported that they enjoyed learning NOS concepts and that it changed their views of science. Classroom observations support this finding, as we viewed several classes where students were engaged in extensive and at times sophisticated discussions regarding NOS ideas. Students also told us they had previously disliked science, but enjoyed learning about the limitations of science and the "human side" of the scientific enterprise. For example, in response to the question "How have your views about science and science classes changed since the beginning of this school year?", students from one of Teacher 5's classes, a high NOS implementation teacher, wrote

> I learned that scientists use their prior knowledge to solve problems. (Teacher 5, student response 1.07)
>
> Now I'm skeptical about most of the stuff we learn. (Teacher 5, student response 1.15)
>
> I used to think there was a method to science, but now I realized that very few people use the scientific method. I also learned that a lot of scientific things are discovered too. (Teacher 5, student response 1.18)
>
> I had always been taught to the book, and "it was always right." My previous teachers never explained how unexact (sic) of an art science can be (and is.). We explored the fact that what is in our books may not always be correct, it is just the most accepted answer. I no longer trust my book, etc., to be the absolute, end all, answer to my science-related questions. Learning about the nature of science has also helped me to look deeper into how scientists operate and how many discoveries came to be (biased and not exact, etc.). I would say that this class has opened my eyes to the way I perceive science to truly be, not this exact study of things and nature that yeild (sic) perfect answers, because in reality science is far from that! But still, it's the best we have. (Teacher 5, student response 1.19)

> At the beginning of the year I thought that scientists were just guys in white lab coats. Now I understand. (Teacher 5, student response 1.24)
>
> Now I know how scientists come up with answers. (Teacher 5, student response 1.26)
>
> I didn't really have any views to begin with, so I can't really say that they changed. (Teacher 5, student response 1.30)
>
> I was taught in previous years that there was a specific way to do science. By following the scientific method. In this class I have learned that there really isn't a scientific method. I know now a better definition of what science is. (Teacher 5, student response 1.38)
>
> I know now that there is more to science than most people think. (Teacher 5, student response 1.39)
>
> I didn't used to like science very well but after having [Teacher 5] for a term my ideas have changed. I still don't want to have science as my career but as far as taking science when I am in college I would really enjoy that. (Teacher 5, student response 1.63)
>
> I viewed science as a bunch of smart people doing high tech big funded research that is really important. But now I view basic research with application as a necessity in order to have applied science anyway. (Teacher 5, student response 1.81)

We have included students' statements from a single class of teacher 5 rather than across classes and teachers to illustrate how pervasive such comments were in the high NOS implementation teachers' classrooms. The specificity and depth of NOS ideas to which students refer is not limited to a few high-achieving students. The number of positive student responses was typical of high-implementation teachers' classes, regardless of the teachers' years of experience or school setting.

Teachers' NOS Understanding and Relation to Instructional Practices

All six study participants expressed a robust understanding of the NOS on the summer NOS course pre- and post-VOSTS assessments and again at the end of the fall semester in which this study took place. Rather than select one of the empirically derived multiple-choice responses, study participants often selected "None of the above choices fits my basic viewpoint" and proceeded to write a response illustrating sensitivity to subtleties with language and ideas related to the NOS. Recall that all six study participants had previously completed two required NOS content courses and elected to complete the NOS pedagogy course. Thus, their excellent understanding of the NOS is unsurprising.

In addition to having a robust understanding of the NOS, all six teachers performed very well on course assignments that required them to apply that understanding to effectively teaching the NOS to secondary school students. All six teachers performed admirably at modifying a 10–20-day science lesson of their choosing so that it more accurately, explicitly, and consistently addresses the nature of science both decontextually and contextually. Teachers used puzzle-solving activities, Gestalt switches, outside materials that addressed the NOS or created opportunities to accurately address the NOS, excerpts from primary source material, class discussions, and assessments that promoted NOS as a cognitive objective.

Interview dialogue also supported participants' understanding of both NOS content and pedagogy. Thus, study participants' understanding of the NOS and how to effectively incorporate NOS instruction in lesson plans was insufficient to explain differences in their NOS teaching practices.

Teachers' Rationales for Teaching the NOS

The raw number and type of rationales provided by teachers prior to the summer course was the same for teachers who later were categorized as low and high NOS implementers. Among teachers who implemented NOS at high levels, the raw number of rationales they provided for teaching the NOS increased from the beginning to the end of the course and increased again at the end of the fall semester of teaching. When examining the categories appearing in Table 12.5, the number of times rationale 4 appeared (NOS helps students understand science content) differed between high and low implementation teachers. None of the teachers provided this rationale prior to the summer course. At the end of the summer course, this rationale was present in all four high implementation teachers' writing task, and was vaguely present in one low-implementation teacher's writing task, although it was combined with "inquiry" and could refer to process skills. At the end of the fall semester, after teaching the NOS to students, three high-implementation teachers cited learning of science content as a rationale to teach NOS. Low NOS implementation teachers did not provide this rationale for teaching the NOS and instead tended instead to focus on more general rationales related to teaching such as "I have to teach it anyway because it is in the standards," "NOS is taught no matter what, so I should teach it accurately," and "NOS improves teaching."

While teachers categorized as low implementers conveyed a robust understanding of NOS content and effective NOS pedagogy, no noticeable changes in their rationales for teaching NOS occurred. The number of coded responses remained stable; in other words, they did not increase or decrease the number of reasons that NOS should be taught. Unlike the high implementers, rationale 4 did not increase over time. Like the high implementers, rationale 4 was missing prior to the course, but unlike the high implementers, this rationale did not appear in their later writing tasks.

Institutional Constraints and Implementation Level

All six teachers in our study cited institutional constraints as hindering their efforts to effectively teach the NOS. This is consistent with the findings of Bell et al. (1997) who found that issues of time and content coverage impeded NOS instruction implementation. Despite these stated concerns, however, this study raises questions about the sufficiency of these constraints to explain teachers NOS implementation practices.

For instance, both low NOS implementers (teachers 3 and 4) cited their inexperience as affecting the extent of their NOS instruction. Both were first-year teachers and stated that they were uncomfortable with unanticipated student responses, and this caused them to decrease the amount of time spent addressing NOS issues. But this reason is suspect because unanticipated student responses also occurred when they both taught science content, yet they persisted in teaching those ideas. Moreover, high NOS implementation teacher 2 was in her first year of teaching and also noted her surprise at student responses to her science content and NOS questions, but she persisted in her efforts at effective NOS instruction.

Low NOS implementation teacher 3 cited concerns with the principal over her classroom management as interfering with NOS instruction. Yet teacher 1 had the highest NOS implementation level and faced open resentment from his science department colleagues who were upset that he wasn't doing precisely what they did with their students. This opposition toward teacher 1's extensive NOS instruction then spread to the principal who then voiced that similar teaching and learning experiences should exist in all biology classes at the school. High NOS implementation teacher 5 also faced similar colleague hostility, and high-implementation teacher 6 noted lack of support/indifference to his NOS instruction. Only high-implementation teacher 2 noted significant freedom, but not encouragement, from science colleagues and the school administration to teach the NOS.

Conclusions and Implications

All six teachers taught the NOS and four of the six did so extensively throughout the fall semester in which this study took place. This conclusion is supported by classroom observations, classroom and lesson material artifacts, and students' reported perceptions. All six teachers drew from the NOS activities presented during the summer NOS course, but the four high NOS implementation teachers incorporated both decontextualized and contextualized NOS instruction whereas the two low NOS implementation teachers limited their NOS instruction to isolated decontextualized instruction. These two low NOS implementation teachers neither planned for contextualized NOS learning experiences nor did they capitalize on NOS opportunities that clearly arose while teaching science content.

All six teachers conveyed an excellent grasp of NOS content and effective NOS pedagogy. All six reported institutional constraints that worked against effective NOS instruction. Both low-implementation teachers noted a lack of support for their efforts to accurately teach the NOS, and reported that other instructional concerns were more pressing to their administrators and colleagues. However, the most severe constraints and even some open hostility toward NOS instruction were faced by teachers 1 and 5, who were both high NOS implementers. Thus, institutional constraints are an insufficient explanation for the level of NOS instruction incorporated by teachers in our study. This does not mean that institutional constraints are unimportant in whether a teacher does or does not place significant attention on

NOS instruction, but obviously the four high-implementation teachers in our study did not permit those institutional constraints to interfere in teaching the NOS.

So the question arises: what about the high NOS implementers might account for their perseverance at teaching the NOS despite the institutional constraints they faced? What *was* clearly different between the high and low NOS implementation teachers in our study is that all four high NOS implementers possessed clear and fervent rationales for teaching the NOS that appeared to compel them to address the NOS in all aspects of their teaching despite the constraints they faced. Interestingly, all four high NOS implementation teachers asserted that NOS instruction helps students learn science content as one of their rationales for why the NOS should be accurately and effectively taught. What these four teachers saw as the precise connection between the NOS and understanding science content was not clear in their writing, but the summer NOS course emphasized the following connections (Clough, 2004):

- Understanding the NOS helps students understand and work from the assumptions that underlie scientific knowledge;
- Understanding the NOS can raise students' interest in science and science classes, thus improving motivation to learn the science content;
- Teaching the NOS improves a science teacher's science content instruction (e.g., explicitly addressing the NOS will make clear the construction and reconstruction of science ideas, and will help students understand that some of the ideas they hold were once held by scientists. This will make clear to both teachers and students the conceptual journey that students must make in understanding contemporary science ideas.).

The four high-implementation teachers' comments and classroom practice were consistent with a view that science content teaching and learning would be improved with NOS instruction seamlessly incorporated throughout science instruction. The two low NOS implementation teachers did not express the same tight link between science content and NOS content, and gave priority to the former.

As noted earlier in this chapter, Lakin and Wellington (1994) wrote that NOS instruction appears to be contrary to "expectations held of science and science teaching in schools, not only by teachers and pupils but also those perceived as being held by parents and society" (p. 186). However, perhaps a more precise representation of the situation may be that attempts to *accurately* portray the NOS are contrary to the expectations held of science teaching in schools! The NOS misconceptions held by many science teachers, their students, administrators, parents, the general public, and promoted in science textbooks coalesce to form a powerful self-supporting network that draws attention to teachers who attempt to accurately portray the NOS. This unsought attention is unlikely to be met with encouragement, and may draw reproach, particularly if a teacher is struggling in any other aspect of his or her teaching. Perhaps a conviction that NOS instruction is not an "add-on" distraction, but rather an integral part of effective content instruction is crucial for teachers to incorporate NOS instruction at high levels despite institutional constraints.

All six teachers in our study stated that they are committed to teaching the NOS, and all did so in some form. But the four high-implementation teachers expressed a more compelling and passionate rationale for teaching the NOS. They were resolute about accurately and effectively teaching the NOS, and were willing (but did not seek) to stand out among their science-teaching colleagues and "buck the system," potentially putting themselves at risk of offending colleagues or having their practices questioned. These high NOS implementation teachers' commitment to accurately and effectively teaching the NOS was also apparent in our classroom observations that made clear they exerted more time and effort preparing to teach the NOS. A passionate rationale for students to accurately understand the NOS, a teacher's willingness to stand out from others regarding teaching practices, and time and effort devoted to teaching appear in our study to be important factors affecting NOS implementation.

While generalizability is limited on a study of six teachers, our study supports the contention that teachers experiencing a NOS course emphasizing the objectives in Table 12.1 will implement the nature of science within secondary science classes, and most at high levels. Teachers in our study cited the value of learning ways to implement NOS instruction within the science content, thus removing the pressure to "add" yet another unit to an already overburdened curriculum. They used activities from the course in their own teaching, and five of the six sought out additional activities, articles, and other resources to incorporate the NOS within the content they taught.

Students are aware they are learning NOS when teachers make the nature of science an explicit part of instruction, and when implemented well, students are very positive about learning NOS concepts. Common responses among students included appreciation for complexity; they enjoyed knowing that multiple methods exist, that scientists can change their minds, that prior knowledge affects what scientists see and the interpretations they make, and that scientific knowledge itself may be open to change. Some student responses conveyed they had questions about NOS issues prior to the course that were finally answered when they studied NOS. For example,

> I never gave much thought to "prior knowledge altering one's perception" but before [teacher 5's] class I would often get into heated debates with my previous science teacher over "the scientific method." I always thought that there isn't just one scientific method and [teacher 5] has now shown me I was right. (Teacher 5, student response 1.58).
>
> I think I was very narrow minded about a lot of things and don't think I really applied myself to try and change my views (mainly because my eighth grade science teacher). Being in this class helped me see that there is more than one way to do almost everything and that most times scientists' ideas are altered because of their other thoughts and feelings. [Teacher 5] explained in detail many things I had questions about. (Teacher 5, student response 1.54).

Thus, while many science teachers view NOS instruction as an "add-on," students in our study expressed appreciation that they are finally learning how science really works, and appear to value NOS instruction. No student in any class of the high-implementation teachers stated that they felt it was a distraction to what they "should be learning," despite this being a common concern among many science teachers.

This study will be continued as additional teachers complete the course. We intend to develop patterns of implementation and to determine what factors most inhibit successful NOS instruction. In the mean time, we have determined that courses designed to promote NOS teaching must address the misconception that the nature of science is an "extra" to be added on to the curriculum. Instead, teachers need both practical strategies to implement NOS instruction within the context of the content they are teaching, and support in developing the view that NOS instruction will help students learn science content. In addition, they need to correctly and consistently identify where in their units they can include NOS concepts and take advantage of those opportunities.

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