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SCIENCE TEACHER EDUCATION

Teachers' Nature of Science Implementation Practices 2–5 Years After Having Completed an Intensive Science Education Program

BENJAMIN C. HERMAN,[1] MICHAEL P. CLOUGH,[2] JOANNE K. OLSON[2]
[1]*Department of Secondary Education, University of South Florida, Tampa, FL 33620, USA;* [2]*School of Education, Iowa State University, Ames, IA 50011, USA*

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ABSTRACT: Few, if any, studies have examined the impact of nature of science (NOS) instruction on science teachers' practices 2 or more years after completing a science teacher education program. Extant studies on preservice and first-year teachers' NOS teaching practices have had disappointing results, with few teachers valuing NOS as a cognitive objective or teaching it in ways consistent with literature regarding effective NOS instruction. In addition, little is known about teachers' specific NOS practices due to a lack of observation protocols to assess teachers' NOS instruction. This study examined teachers' NOS instructional practices 2–5 years after completing an intensive secondary science education program that included a NOS course and attention to NOS instruction throughout all other science education coursework. Twelve of the 13 study participants explicitly taught NOS, and 9 of the 13 did so at moderate to high levels. This paper also presents a NOS Classroom Observation Protocol (NOS-COP) designed to make evident many facets of teachers' NOS implementation practices that have not always been clear in prior research. This study raises important issues about achieving the goal of NOS instruction. Accurate and effective NOS instruction appears achievable, but may require far more effort than found in typical science teacher education programs. © 2013 Wiley Periodicals, Inc. *Sci Ed* **97:**271–309, 2013

Correspondence to: Benjamin C. Herman; e-mail: bcherman@usf.edu

INTRODUCTION

The "nature of science" (NOS) is a phrase commonly used in science education to encompass issues such as what science is and is not, how science and scientists work, the ontological and epistemological foundations of science, and how science and society impact one another (Clough, 2006; McComas, Clough, & Almazroa, 1998). Interest in promoting students' understanding of NOS has a long history, appearing at least as far back as the mid-nineteenth century (Matthews, 2012), persisting at varying levels through the twentieth century and became a focus of science education reform in the late 1980s with the publication of *Project 2061: Science for all Americans* (American Association for the Advancement of Science [AAAS], 1989). That book and other U.S. science education reform documents that followed (AAAS, 1993, 2001; National Research Council [NRC], 1996) positioned students' understanding of NOS as central to scientific literacy. Expectations for promoting students' understanding of NOS appear in international standards documents (McComas & Olson, 1998) and in most U.S. state science standards (McComas, Lee, & Sweeney, 2009). The most recent U.S. science education reform document (NRC, 2011) emphasizes both science and engineering practices, and NOS understanding is crucial for understanding the differences, similarities, and relationships between those two disciplines.

Since the late 1980s, much research has been conducted on students' and teachers' NOS understandings and on pedagogical decision making and practices that effectively help students develop more accurate NOS understandings. Much has been learned about NOS teaching and learning. However, despite all that has been learned and the continued emphasis on understanding NOS as a goal for science education, from primary through postsecondary school, NOS is rarely addressed in an accurate and effective manner. Science teachers often do not consider NOS an important educational objective and therefore do not explicitly plan to teach NOS (Abd-El-Khalick, Bell, & Lederman, 1998; Bell, Lederman, & Abd-El-Khalick, 1997; King, 1991). Reflecting these and other studies, 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).

Against this backdrop, the study reported here investigated the NOS teaching practices of 13 teachers having experienced a demanding secondary science teacher education program that extensively addressed the role of accurate and effective NOS instruction in science teaching. Understanding teachers' NOS implementation practices and the extent that science teacher education programs can prepare teachers who *do* accurately and effectively teach NOS is a crucial step in efforts to improve NOS teacher education efforts. Because the teachers in this study completed a science teacher education program with substantial differences from other studies, findings reported here may provide important information regarding efforts to prepare science teachers who accurately and effectively teach NOS.

NOS in Science Education

Not all are in agreement regarding what is meant by "NOS." Some science educators, influenced by particular scholars in the field of science studies and work on public engagement with science in real-world contexts, argue for a variety of perspectives on what is meant by "NOS" and where boundaries should be drawn. Harding (1998), Knorr-Cetina (1999), Rudolph (2000), and others maintain that science is so very diverse, contextual, and nuanced, that the construct "NOS" has questionable value. This sort of position reflects a mode of thought known as "discrimination" (McKeon, 1994) and "perspectival"

(Owen, 2003), and such philosophical debates appear to some extent in all fields of study. As McKeon (1994) noted, any problem, pushed far enough, becomes philosophical.

That said, what is meant by NOS and what NOS ideas are worth exploring must be seriously deliberated because identifying desired educational outcomes and standards does privilege particular ideas over others. Thus, these matters ought to be carefully considered, while acknowledging that because schools face significant time and resource constraints, decisions must be made regarding what children are taught. To begin, that school science does convey strong messages about what science is and a host of other issues regarding the nature of the discipline is undeniable. For instance, Clough (2006) writes,

> . . . despite teachers' intentions, science courses cannot escape conveying an image of the NOS to students. Teachers' language (Benson, 1984; Dibbs, 1982; Lederman, 1986; Zeidler & Lederman, 1989), cookbook laboratory activities, textbooks that report the end products of science without addressing how the knowledge was developed, misuse of important words having special meaning in a science setting, and traditional assessment strategies are just some of the ways students develop conceptions about the NOS. Ever present in science content and science teaching are implicit and explicit messages regarding the NOS. The issue is not whether science teachers will teach about the NOS, only what image will be conveyed to students. (p. 464)

While students' ideas regarding NOS are contextual and complex, they do hold many problematic conceptions. These conceptions exist and persist despite disagreements among academics regarding what is meant by NOS, and these notions regarding NOS do play out in the public's engagement with science (Rudolph, 2007).

So the issue really is one of what does the science education community wish to accomplish regarding teaching and learning about NOS. We recognize that even among scholars who focus on practical issues of NOS instruction in schools, differences exist in how NOS is defined. For example, Lederman (2007) and McComas (2004) focus on particular NOS tenets. This approach, while likely annoying to scholars taking a perspectival approach, reflects a mode of thought called "construction" by McKeon (1994) and "atomistic" by Owen (2003). This mode of thought is consistent with most schooling in the United States and is illustrated by defining objectives and developing assessments closely aligned with those objectives.

The authors of this paper, and the science teacher education program that participants in the study reported here completed, eschew both the indefinite and impractical (for the purposes of schooling) perspectivalists' position and the narrow atomistic position reflected by NOS tenets. Our position, termed "resolution" by McKeon (1994), focuses on NOS as nuanced questions (Clough, 2007, 2011a) that students should ponder in the context of the work of authentic science, scientists (Clough, 2011b), and public engagement with science (Allchin, 2011; Mitchell, 2009). Resolution is characterized by an emphasis on problems about which one inquires. As with all philosophical positions, we at times draw practical demarcations, admitting that they do not correspond to an absolute truth, but are well-reasoned, informative, useful, and provide an entry point for students to comprehend this thing called science well enough to understand its contextual nature and engage in public policy issues involving science. Thus, for the purposes of science education,

> While some characteristics regarding the NOS are, to an acceptable degree, uncontroversial and have clear implications for school science teaching (Eflin, Glennan, & Reisch, 1999; McComas et al., 1998; Smith et al., 1997), most are contextual with important and complex exceptions. Where consensus does not exist, the key is to convey a plurality of views

> so that science teachers and students come to understand the importance of the issues and complexities regarding the NOS. Even in NOS matters having widespread agreement, conceptual understanding rather than declarative knowledge should be sought. This is critical as the point of a progressive education, including an understanding of the NOS, is not to indoctrinate, but to educate students about relevant issues, their contextual nature, and reasons for differing perspectives (Matthews, 1997). (Clough, 2006 , pp. 463–464)

EFFECTIVELY TEACHING NOS

Much has been learned about teacher decision-making and teaching practices that promote greater understanding of NOS, and much of this is unsurprising as it is congruent with more general effective science teaching practices. First, teachers must see NOS understanding as an important instructional objective that they purposely teach toward, just as they see fundamental science ideas as important instructional objectives that are planned for conscientiously and purposely taught (Lederman, 1999). Second, when addressing NOS, teachers should draw students' attention to targeted NOS ideas in a manner that has them think about those ideas (e.g., Abd-El-Khalick & Lederman, 2000; Akindehin, 1988). Finally, assessing students' NOS understanding is an important part of effective NOS instruction (Clough, 2011a) so that teachers can make informed pedagogical decisions, and because "assessment gives clear messages to students about what is important in the subject" (Dall' Alba et al., 1993, p. 633).

Moreover, researchers have raised the issue that NOS understanding and learning appears to be related to the context in which it is addressed (Brickhouse, Dagher, Letts, & Shipman, 2000; Driver, Leach, Millar, & Scott, 1996; Kishfe & Abd-El-Khalick, 2002; Ryder, Leach, & Driver, 1999; Schwartz, Lederman, & Crawford, 2004). These studies addressing the role of context in NOS learning and understanding provide important considerations for NOS teaching and learning. First, NOS experiences will be framed in the context of learners' prior understanding and experiences. Second, students' ability to understand and apply targeted NOS themes appears linked to how familiar and concrete is the science content of the lesson in which those NOS ideas are embedded.

Thus, in addition to the need for NOS instruction to be overt and reflective, Clough (2006) argues that promoting deep and robust NOS understanding also demands that NOS instruction occurs in a variety of contexts and with extensive scaffolds between those contexts. To this end, NOS instruction should occur along what he refers to as the decontextualized to highly contextualized NOS continuum [i.e., devoid of science content (decontextualized), unified with scientific inquiry and content (moderately contextualized), and embedded within historical and contemporary science examples articulating the development of science ideas (highly contextualized), hereafter referred to as the *NOS context continuum*], with explicit scaffolds back and forth along this continuum that help students develop deep and robust NOS understandings that reflect varying contexts and perspectives. See Clough (1997, 2006, 2011a) for specific examples of what might be seen and heard in effective NOS instruction.

PRIOR EFFORTS TO PROMOTE NOS INSTRUCTION

Abd-El-Khalick et al. (1998) studied the NOS teaching practices, and factors affecting those practices, of 14 secondary preservice teachers in a fifth-year cohort master of arts in teaching (MAT) program. The program clearly emphasized NOS and its crucial role in reform-based practices. Despite these extensive efforts, few of the preservice teachers indicated that teaching NOS was an important goal in their science teaching, only one taught NOS in the context of science content, and few planned to explicitly address NOS. None of the participants indicated they formally assessed their students' conceptions of NOS.

Bell et al. (2000) studied whether changing the sequence of instruction in the preservice program studied by Abd-El-Khalick et al. (1998) would affect preservice teachers' NOS teaching practices. Nine of the eleven participants in this study explicitly implemented NOS instruction. Five of the eleven participants included NOS or aspects of NOS as one of their primary science teaching goals. However, participants generally failed to include NOS in formal instructional objectives and only one indicated she formally assessed students' conceptions of NOS.

Few studies have followed graduates of science teacher education programs emphasizing NOS to determine their NOS teaching practices after having been away from their preservice program for at least 1 year. Lederman (1999) investigated the NOS teaching practices of five experienced inservice teachers and factors affecting those practices. Notably, all participants had considerable curricular freedom, faced no imposed assessment requirements, and worked in school districts having "students' understanding of the nature and limitations of science" as a curriculum objective (Lederman, 1999, p. 919). Despite possessing NOS views consistent with science education reform documents (AAAS, 1990, 1993; NRC, 1996), none of the teachers in the study explicitly and clearly addressed NOS.

Schwartz and Lederman (2002) investigated two beginning teachers' efforts to learn and teach NOS and factors that affected their implementation efforts. With the exception of having completed a science teaching research internship coupled with explicit NOS instruction (in place of a part-time teaching experience), the preservice program sequence these two teachers experienced resembled that outlined in Bell et al. (2000). During their first year of teaching, both teachers demonstrated knowledge of NOS and NOS pedagogical content knowledge (PCK). Despite explicitly planning and implementing NOS experiences early in the school year in a manner resembling activities used in the program, both teachers struggled to effectively teach NOS within the context of science content and inquiry over the academic year. These teachers indicated their implementation of explicit NOS instruction was infrequent because of institutional constraints such as having to devote considerable time to teaching required science content.

The literature reviewed here clearly suggests that even when possessing an accurate understanding of NOS, teachers still often neglect to implement accurate and effective NOS teaching practices in their science classrooms. Most of the reviewed studies focused on the NOS teaching practices of novice (preservice and first-year) science teachers. However, the single small study of experienced science teachers facing little resistance to NOS had disappointing results. The studies above make clear that accurately and effectively teaching NOS remains an elusive goal in science education reform efforts.

METHODOLOGY

Intent of Study

The intent of this study is to determine the type and level of NOS teaching practices exhibited by graduates of an extensive and demanding secondary science teacher education program, and the extent those practices reflect and went beyond what was modeled in their science teacher education program.

Research Context

The science teacher education program that study participants completed was designed to prepare highly qualified secondary science teachers who understand how people learn

(Bransford, Brown, & Cocking, 2000) and employ reform-based practices (AAAS, 1990, 1993; NRC, 1996, 2011) based on the best available educational research implemented in a holistic manner (Clough, Berg, & Olson, 2009) to create powerful learning environments. Among many crucial objectives of this program is preparing preservice teachers to effectively teach NOS in a manner that is congruent with contemporary science education research (Abd-El-Khalick & Lederman, 2000; Clough, 2006; Khishfe & Abd-El-Khalick, 2002; Lederman, 1992). This program employs a cohort model and consists of multiple science methods courses (three for undergraduates and four for graduate licensure students) and a required Nature of Science and Science Education course. The two science education faculty members in this program consistently model the reform-based practices they expect from their students, and NOS is a recurring theme across science education coursework.

The science education portion of the preservice program is directed at *educating* (as opposed to training) teachers so that they deeply understand research-based teaching, refer to that research base and its synergistic interrelationships when making instructional decisions (Clough et al., 2009) and implement effective science teaching practices reflecting that research and promoting desired science education goals. The program, reflecting what is known about effective teacher education, (1) is longitudinal, occurring over four semesters; (2) is experience-based, requiring extensive public school science teaching; (3) utilizes a spiraling curriculum (i.e., concepts, strategies, and teacher behaviors are readdressed in new and more complex situations as students move through the program); (4) requires multiple quantitative and qualitative student self-evaluations; and (5) emphasizes NOS and its implications for science education. The science teacher education component of the program appears in Table 1.

Undergraduate and graduate students complete the program together as a cohort group, although undergraduates complete their student teaching experience at a later time. All students together complete multiple science methods courses and a required Nature of Science and Science Education course. The two faculty members who teach the science education courses have both received several recognitions for their teaching.

Understanding NOS and effective NOS pedagogy is a significant and recurring part of the program. However, NOS is but one of many important goals for science education. Thus, throughout the program, teaching and learning about NOS is placed within the broader context of effective science teaching. For instance, students' difficulty in learning science is often linked to the counterintuitive nature of scientific processes and knowledge (Cromer, 1993; Matthews, 1994; Wolpert, 1992). Moreover, deeply understanding science content is linked to understanding NOS (Matthews, 1994; Rudolph & Stewart, 1998) and other science education goals (Clough et al., 2009). The metaphor of border crossing (i.e., acknowledging the cultural values inherent in science) is stressed both to understand NOS and to help teachers understand and more effectively teach counterintuitive science ideas.

During the first science education course, preservice teachers learn about the ongoing problems in science education, including inaccurate portrayals of NOS. At this same time, each student spends a minimum of 20 hours in schools observing science teaching and comparing what they see to science education reform documents. The following semester, students complete Science Methods I, Nature of Science and Science Education, and a 60+ hour semester-long internship experience. During this semester, students deeply examine NOS via questions (Clough, 2007) rather than tenets, the role it plays in science literacy and effective science teaching, and what effective NOS pedagogy entails. The instructor of the NOS course draws from and models NOS pedagogical practices appearing in the

TABLE 1
Science Teacher Education Program Structure, Sequence, Credits, and Contact Hours

Undergraduate Science Teacher Education Program			
Sophomore Year	Junior Year		Senior Year
Spring Semester	Fall Semester	Spring Semester	Fall or Spring Semester
• Introduction to the complexities of learning and teaching science (2 credits, 20 contact hours) • 20+ observation hours	• Science Methods 1 (2 credits, 50 contact hours) • School Internship (2 credits, 60+ hours) • Nature of Science and Science Education (3 credits, 45 contact hours)	• Science Methods II (2 credits, 50 contact hours) • School Internship (2 credits, 60+ hours)	• Student Teaching (12 credits, 14 weeks)

Graduate Science Teacher Education Program (Master of Arts in Teaching)			
Summer 1 Semester	Fall Semester	Spring Semester	Summer 2 Semester
• Introduction to the complexities of learning and teaching science (2 credits, 20 contact hours) • 20+ observation hours	• Science Methods 1 (2 credits, 50 contact hours) • School Internship (2 credits, 60+ hours) • Nature of Science and Science Education (3 credits, 45 contact hours)	• Science Methods II (2 credits, 50 contact hours) • School Internship (2 credits, 60+ hours) • Student Teaching (12 credits, 14 weeks)	• Advanced Pedagogy in Science Education (3 credits, 45 contact hours)

Ten study participants completed an elective "Restructuring Science Activities" course the summer after completing Science Methods II.
The above is the science education specific course work preservice teachers must complete. Other education courses (e.g., education psychology, multicultural education) must also be completed.

research and from his prior secondary science classroom experience teaching NOS (again, see Clough (1997, 2006, 2011a) for classroom examples illustrating how NOS is taught). Emphasizing NOS questions, context and complexity, the overarching theme of this course is that NOS should be accurately, effectively, and consistently addressed in the context of science content instruction, not simply incorporated periodically in a science course (Clough & Olson, 2004). For instance, the final project in the NOS course has students modify a science unit so that accurately and effectively teaching NOS is seamlessly part of teaching the science content in the unit.

During the spring semester, all preservice teachers complete Science Methods II and a 60+ hour internship. Graduate licensure students also complete a 14-week student teaching experience. NOS, along with all other science education goals, remains a theme through the Science Methods II course. Students must demonstrate reform-based science teaching practices and submit an extensive 10-day lesson plan that, among other things, must accurately, effectively, and consistently address NOS in the context of the science content being addressed. Again, NOS is promoted as a synergistic part of effective science teaching—a goal that is crucial because it and other science education goals are equal partners in creating a science literacy that is greater than the sum of the constituent parts (Clough et al., 2009). During the second summer term, all graduate licensure students complete a fourth science methods course (Advanced Pedagogy in Science Education) and their master's degree project. Many preservice teachers (including 10 of the 13 teachers in this study) also complete an optional Restructuring Science Activities course. This course focuses on the modification of laboratory activities and other everyday science activities so they are more mentally engaging and congruent with how students learn science, NOS, and the *National Science Education Standards* (NRC, 1996).

Study Participants

Table 2 provides information regarding the 13 secondary science teachers who participated in this study. Participants were in their 2nd to 14th year of professional teaching in schools, and none were currently teaching in schools that expected or encouraged attention to NOS in science classes.

All but one of the study participants completed their preservice science teacher education program at the same large midwestern university in the United States. Of the 12 participants who graduated from this preservice program, 10 earned their teaching license in a 15-month postbaccalaureate MAT program and the remaining two earned their teaching license in the undergraduate program. All 12 completed the same three required secondary science methods courses and a required Nature of Science and Science Education course. Moreover, all 12 completed their science education coursework in cohort groups, a feature of the science teacher education program that was purposely designed to encourage collaboration. Nine of these twelve study participants completed an optional Restructuring Science Activities course that addresses how to modify cookbook activities into inquiry activities. The 13th participant was a teacher in his 14th year, but who was in his second year of teaching after having completed an M.S. graduate program at the same midwestern university (which included completing with a cohort group the Nature of Science and Science Education course, Advanced Pedagogy in Science Education course, and the Restructuring Science Activities course).

The 13 study participants completed the aforementioned science teacher education program from spring/summer 2005 through spring/summer 2008. During this 4-year period, 62 total students completed the program. Of these 62 students, 11 never taught—choosing instead to enter medical school, science Ph.D. programs, or careers in industry. Of the 51 remaining individuals, 1 could not be located and 10 taught outside the state—too distant to include in the study. Thus, 40 program graduates remained as potential study participants and 13 agreed to participate and completed the informed consent documents. While we cannot claim that the 13 study participants are a random sampling of the initial 62 program graduates or of the 51 teaching at the time this study took place, we have no evidence that they stand out from the larger pool of program graduates.

TABLE 2
Study Participants

Participant	Gender	Age (Years)	Years of Teaching	Year at School	School Setting	Courses Taught
Luke	M	29	4	Second	Suburban	Earth science
Andrew	M	27	4	Fourth	Suburban	General science
John	M	39	14 (second year postprogram)	Eleventh	Rural	Physics
Matthew	M	26	3	Third	Suburban	Chemistry
Sharon	F	25	2	Second	Rural	General science and biology
Isaac	M	39	2	Second	Rural	Chemistry
Mark	M	32	5	Fourth	Suburban	Environmental science and physics
Peter	M	41	2	First	Suburban	Biology and chemistry
Carey	F	26	2	Second	Urban	Environmental science and biology
Maddy	F	26	5	Fifth	Suburban	Biology and advanced biology
Mary	F	25	3	Second	Suburban	General science and biology
Thomas	M	49	5	Fourth	Suburban	Earth science and biology
Philip	M	26	4	Second	Suburban	Environmental science and anatomy and physiology

Abbreviations: F, female; M, male.

Study Approach and Data Collection

This study used qualitative methods grounded in a naturalistic inquiry approach with emergent design flexibility (Maxwell, 2005; Patton, 1990) to investigate the NOS teaching practices of 13 science teachers in their second to fifth year of teaching after having completed a secondary science teacher education program. The teachers were informed the intentions of this study were to analyze their teaching practices so recommendations could be made to improve their science teacher education program. Because participants were not aware that this particular study focused on their NOS teaching practices, their NOS teaching practices more likely reflected their typical practices. The first author conducted the classroom observation visits and interviews. Having previously completed this same science teacher education program prior to any participant in this study, he was quite familiar with the program from a student's perspective. Importantly, he was not at the university during the 4 years that participants in the study were immersed in the science teacher education program. Thus, he was not in a position of authority relative to the study participants, which can impact study participants' conduct during the study and the information they share (Patton, 1990).

Classroom observation data and extensive instructional artifacts (e.g., handouts and tests) were collected over the fall 2009 semester to determine teachers' NOS instructional practices. One study participant was observed twice, and all other participants in this study were observed a minimum of three times. All but two study participants teach more than one science discipline, and/or level of course difficulty within a science discipline (e.g., general chemistry and advanced chemistry). Because science teachers often teach several science subjects, effort was made to observe any single teacher teaching the same course. Extensive fieldnotes were taken during observations and included the layout of the room (for indicators of NOS displays and other indicators of NOS emphasis) and the teacher's practice (e.g., interactions with students, instance and kind of NOS instruction, level of NOS contextualization, and implementation of inquiry). Instructional artifacts for the observed courses were collected biweekly and included daily activities, lesson plans, readings, and laboratories. These data sources were the basis for judging participants' NOS implementation using the Nature of Science Classroom Observation Protocol (NOS-COP) described below and appearing in Appendices A and B.

Because teachers must understand NOS to accurately teach it, this study also assessed study participants' NOS understanding to ensure that observed practices are not due simply to their having poor NOS understanding. Participants' NOS understanding was determined using six items from the Student Understanding of Science and Scientific Inquiry (SUSSI) questionnaire (Liang et al., 2008) and four additional SUSSI-like items. Table 3 lists the NOS construct assessed by each of the 10 items. For two important reasons, study participants' NOS understanding was assessed *after* determining their NOS implementation practices. First, we were concerned that a NOS assessment at the beginning of the study might impact study participants' decisions regarding NOS instruction. Second, because we had no a priori knowledge about teachers' NOS understanding, it could not influence our judgments about the participants' NOS implementation practices.

Each of the 10 items on the modified SUSSI evaluates the understanding of a NOS construct via four Likert subitems and a writing prompt. Based on combined Likert and written responses, each teacher's understanding of the 10 NOS constructs was rated as "naïve," "transitional," or "informed." An overall NOS understanding rating was produced for each teacher based on the percentage of the NOS constructs for which the teacher was categorized as possessing a "naïve," "transitional," or "informed" understanding. A teacher's overall NOS understanding was rated "informed" if at least 70% of the NOS constructs were judged to be informed. A teacher's overall NOS understanding was rated "naïve" if at least 70% of their NOS constructs were judged to be naïve. In all other cases, a teacher's overall NOS understanding was rated as "transitional." A more detailed

TABLE 3
Modified SUSSI NOS Constructs

Item 1	Scientific observations and interpretations
Item 2	Scientific theories
Item 3	Scientific laws compared to theories
Item 4	Social and cultural influences on science
Item 5	Role of imagination and creativity in scientific investigations
Item 6	Extent that scientists follow a single scientific method
Item 7	Social interaction among scientific researchers
Item 8	Science (naturalistic explanations) and religion (supernatural explanations)
Item 9	Time required for developing and accepting credible scientific ideas
Item 10	Scientific ideas: Discovered and/or invented?

TABLE 4
Participants' Summative NOS Understanding Based on the Percentage of Modified SUSSI NOS Constructs for Which They Demonstrated an Informed, Transitional, or Naïve Understanding

Participant	Informed	Transitional	Naïve	Not Classifiable	Summative NOS Understanding
Luke	100	0	0	0	Informed
Andrew	90	10	0	0	Informed
Matthew	90	10	0	0	Informed
John	70	30	0	0	Informed
Sharon	60	40	0	0	Transitional
Isaac	60	20	0	20	Transitional
Mark	30	0	0	70	Not classifiable
Peter	100	0	0	0	Informed
Carey	60	40	0	0	Transitional
Maddy	70	30	0	0	Informed
Mary	10	90	0	0	Transitional
Thomas	30	70	0	0	Transitional
Phillip	20	80	0	0	Transitional

description of these teachers' NOS understanding appears in Herman, Olson, and Clough (2011). Table 4 shows that 6 of the 13 teachers' summative views of NOS were informed. Six of the remaining seven teachers' summative views of NOS were transitional. One teacher's NOS understanding was not classifiable because he failed to complete a majority of the modified SUSSI's qualitative prompts.

NOS-COP Development

To ensure a more transparent and consistent account of study participants' NOS implementation practices, the authors created a NOS-COP evaluation instrument (see Appendices A and B). The NOS-COP is a tool for classifying NOS implementation based on guidelines (e.g., NOS accuracy, explicit referral to NOS, and level of NOS contextualization) informed by established science education literature (Abd-El-Khalick & Lederman, 2000; Clough, 2006; Khishfe & Abd-El-Khalick, 2002; Khishfe & Lederman, 2006) and follows the same format as the Local Systemic Change Classroom Observation Protocol (LSC-COP) (Horizon Research Inc., 2006). The congruency of the NOS-COP with the LSC-COP enables researchers to consider teachers' NOS implementation and science teaching practices more broadly. Just as use of the LSC-COP is to be preceded by a teacher interview so that the context of the observed lessons and artifacts can be better understood, in this study unstructured interviews were conducted with study participants prior to and after observing lessons to acquire a more comprehensive and accurate view of observed lessons. Analyzing, coding, and cross-comparing teachers' classroom observations and artifacts (using exemplars as a guide) across several categories encourages attention to the triangulation of data sources and raises the level of transparency in our work reported here.

Scores on NOS-COP categories range from 1 to 5 and represent the degree that an observation or artifact reflects effective NOS instruction. A score of 1 on a NOS-COP category means that lessons or artifacts were not reflective of NOS instruction outlined in contemporary science education research, whereas a score of 5 means that they were extremely reflective of NOS instruction outlined in contemporary science education research. A rating of not applicable (N/A) appears in the event that a teacher's lesson or set of artifacts did not possess substantial evidence to award a rating for a particular subitem.

Exemplars congruent with the general descriptors on the NOS-COP coding scheme were derived early in the study through the first author repetitively analyzing, coding, and cross-comparing data sources from participating teachers. This process was reiterated until the NOS-COP category scores and general descriptors were accurately matched with an exemplar. Once exemplars were selected, all three authors independently reviewed and cross-compared the exemplars and then came to full agreement that the exemplars characterized the NOS-COP subitem scores and general descriptors of NOS teaching practice. After the exemplars were determined, each teacher's NOS implementation level was determined through reanalyzing classroom observations and artifacts using the NOS-COP.

Data Analysis. Classroom observations and artifacts were analyzed, coded, compared and triangulated using the NOS-COP and a coding scheme (see Appendices A, B, and C) that specifically addressed the extent that those observations and artifacts reflected and extended beyond the NOS instruction promoted by their preservice program. NOS-COP categories A and B were used to assess the extent that inquiry and/or historical/contemporary accurate examples of science were present and afforded opportunities to effectively address NOS. More specifically, NOS-COP category A acknowledges that when science is taught as and through inquiry more opportunities exist for making accurate connections to NOS. Therefore, classroom observations or lesson artifacts reflecting inquiry teaching would be rated higher on NOS-COP category A. NOS-COP item B acknowledges that teachers who incorporate historical/contemporary examples of science in action (e.g., readings presenting current or past science debates, multimedia showing scientific research, stories about scientific developments) will have more opportunities to draw their students' attention to NOS and have them think about it. Therefore, NOS-COP item B assesses the extent that these kinds of opportunities appear in classroom observations and lesson artifacts, and how conducive they are for teachers to use for drawing their students' attention to NOS and having them think about it. These two measures were considered separately because teachers may implement inquiry and historical/contemporary examples of science, but need not do so together.

NOS-COP categories D through I were used to measure the extent that NOS was actually implemented by the teacher. Specifically, these subitems measured the accuracy, explicitness, reflectivity, and scaffolding along the NOS context continuum present in participants' NOS instruction. For each teaching observation, NOS-COP categories D through I were averaged to develop an overall lesson NOS implementation score. These individual lesson scores were then averaged to develop a mean NOS observation implementation score for each teacher across all observed lessons. A mean NOS artifact implementation score was also calculated by averaging NOS-COP categories D through I for each participant's NOS-related artifacts as a whole. Importantly, a participant may have had a few long-term assignments such as term papers that deeply addressed several NOS ideas, whereas others may have had many artifacts such as "bell ringers" that portrayed NOS in smaller increments and more superficially. Because of this, rather than focusing on the number of artifacts collected, or the percentage that directly portrayed NOS, artifacts were analyzed to determine consistency and depth of NOS instruction over the course of the study and to provide triangulation with observations.

A composite NOS implementation score for each participant was calculated by averaging his or her mean NOS observation and mean NOS artifact implementation scores. Each teacher was rated as a high, medium, or low NOS implementer based on composite

TABLE 5
Study Participants' NOS Understanding and Implementation Levels

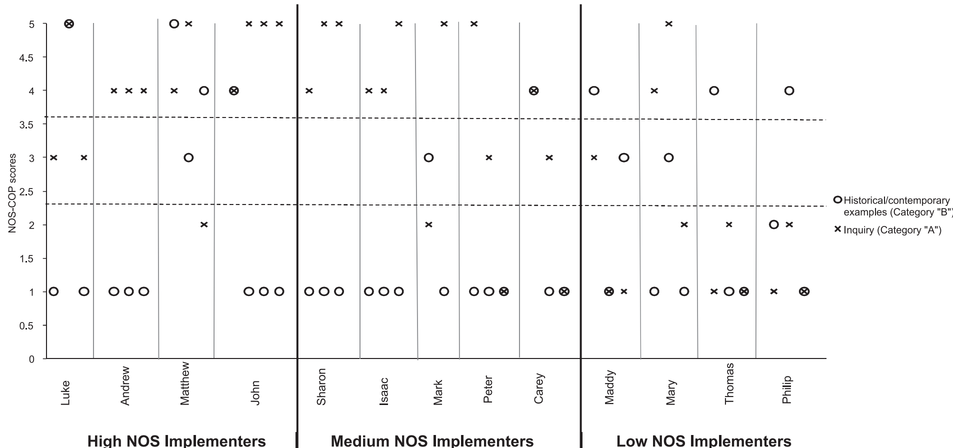
Participant	Summative NOS Understanding	Mean NOS Observation Score	NOS Artifact Score	Composite NOS Implementation Score	Composite NOS Implementation Level
Luke	Informed	4.2 (high)	4.3 (high)	4.3	High
Andrew	Informed	4.0 (high)	4.5 (high)	4.3	High
John	Informed	3.4 (med)	4.2 (high)	3.8	High
Matthew	Informed	3.6 (high)	3.7 (high)	3.7	High
Sharon	Transitional	3.5 (medium)	3.5 (medium)	3.5	Medium
Isaac	Transitional	2.3 (medium)	3.3 (medium)	2.8	Medium
Mark	Unclassifiable	2.9 (medium)	2.7 (medium)	2.8	Medium
Peter	Informed	2.1 (low)	2.7 (medium)	2.4	Medium
Carey	Transitional	2.1 (low)	2.5 (medium)	2.3	Medium
Maddy	Informed	1.8 (low)	2.0 (low)	1.9	Low
Mary	Transitional	1.7 (low)	2.0 (low)	1.9	Low
Thomas	Transitional	1.7 (low)	1.0 (low)	1.4	Low
Phillip	Transitional	1.1 (low)	1.3 (low)	1.2	Low

NOS implementation scores. The cutoff values for NOS implementation levels were 1 to <2.3 = low, 2.3 to <3.6 = medium, and ≥ 3.6 = high. The rationale for parsing the three levels along a 5-point scale, starting at 1 and increasing in approximate increments of 1.3, was to retain congruency between the NOS-COP and LSC-COP scales. Vignettes illustrating the characteristic NOS teaching practices of high, medium, and low NOS implementers appear in Appendix B. Finally, to determine the extent that study participants' NOS instructional practices merely reflected and/or went beyond what was modeled in their science teacher education program, a coding scheme (Appendix C) was used to situate each lesson or NOS-related artifact into one of five categories (*incongruent, unclassifiable, replication, mixed congruency,* and *extension*).

FINDINGS

Using the methodology described above, 4 of the 13 study participants were rated as high overall NOS implementers, 5 were rated as medium overall NOS implementers, and the 4 remaining participants were rated as low overall NOS implementers (Table 5). Three of the four low overall NOS implementers did implement NOS instruction consistent to some extent with what was taught and modeled in their secondary science teacher education program.

Participants' overall NOS artifact score was consistent with their overall observed NOS teaching practices (Table 5). NOS instruction observed in lessons and lesson artifacts occurred primarily in the context of inquiry activities. The extent that participants' observed lessons and lesson artifacts contained inquiry activities and/or information regarding authentic research (historical or contemporary) was associated with the extent that NOS was accurately and effectively incorporated. Study participants appeared far less capable of capitalizing on NOS instructional opportunities when they were in the midst of presenting science content or leading class discussions regarding science content. Study participants also struggled to effectively help students connect NOS ideas raised in one context (e.g., during an inquiry activity) to the same NOS ideas in another context (e.g., in a historical



NOS-COP Rating Range	NOS-COP Categories			NOS-COP Categories			NOS-COP Categories		
	Total	A	B	Total	A	B	Total	A	B
High (≥3.6)	14	10	4	10	9	1	5	2	3
Med (2.3–3.6)	3	2	1	3	2	1	3	1	2
Low (1–<2.3)	9	1	8	15	3	12	16	9	7

Figure 1. NOS-COP Categories A and B coding: Opportunities for accurately and effectively addressing NOS.

or contemporary science example). In lessons that were not well suited for accurately reflecting aspects of NOS, study participants rarely drew their students' attention to, and had them think about, how the lesson departed from authentic science.

The following sections provide detailed findings regarding high, medium, and low NOS implementers. We encourage reference to Appendices A (NOS-COP instrument), B (vignettes illustrating the characteristic NOS teaching practices of high, medium, and low implementers), and C (coding scheme for determining the extent that participants' artifacts and lessons reflected and/or went beyond their teacher education program's promotion of NOS instruction) while reading these more detailed findings.

High NOS Implementers

Observed Lessons. Figure 1 presents for each study participant the extent that their *observed lessons* had clear opportunities for accurately and effectively addressing NOS. Three of the four overall high NOS implementation study participants conducted multiple lessons that were coded 4 or higher on either NOS-COP categories A (lesson that taught science through inquiry) or B (lesson that incorporated reference to the authentic work of scientists).

High NOS implementers took full advantage of the platform their instruction provided to draw students' attention to, and have them think about, embedded NOS issues. Eleven of the thirteen lessons conducted by the four high NOS implementation teachers scored "4" or "5" for explicitly addressing NOS in the context of science content being taught (NOS-COP category F) and for making explicit NOS ideas implicit in inquiry activities (NOS-COP category G). Furthermore, 10 of the 13 lessons conducted by high implementers scored "4" or above for asking questions that engaged students in thinking about NOS ideas in the lessons (NOS-COP category I). Several questions asked by high implementation teachers appear in the NOS-COP as exemplars in Appendix A. High implementers' NOS portrayals were also highly accurate, thus reflecting their NOS understanding. All high NOS implementers consistently scored "4" or "5" on NOS-COP category D.

Even high NOS implementation teachers struggled at drawing students' attention to how NOS ideas raised in different contexts (e.g., NOS ideas in black box activities, NOS ideas in inquiry activities, and NOS ideas in authentic historical or contemporary science research examples) were similar or different (NOS-COP category H). Only 8 of their 13 observed lessons contained moderate-to-substantial scaffolding along the NOS context continuum (Clough, 2006). High NOS implementers were as unlikely as other study participants to explicitly draw students' attention to how their *lesson structures and pedagogical practices* distorted NOS (e.g., cookbook activities or presenting final form science content with no explanation of how it was developed) (NOS-COP category E).

High NOS implementers taught NOS in a manner congruent with what they experienced in their science teacher education program. Furthermore, Figure 2 shows that 11 of the 13 lessons by these teachers addressed targeted NOS ideas and activities in novel and modified contexts that went beyond what they experienced in their teacher education program's promotion of NOS instruction. Exceptions to this were two lessons conducted by John where attempted NOS instruction was present. However, difficulties with asking effective NOS questions in these lessons prevented John from explicitly addressing NOS in a manner that was fully congruent and went beyond what was presented in the science teacher education program.

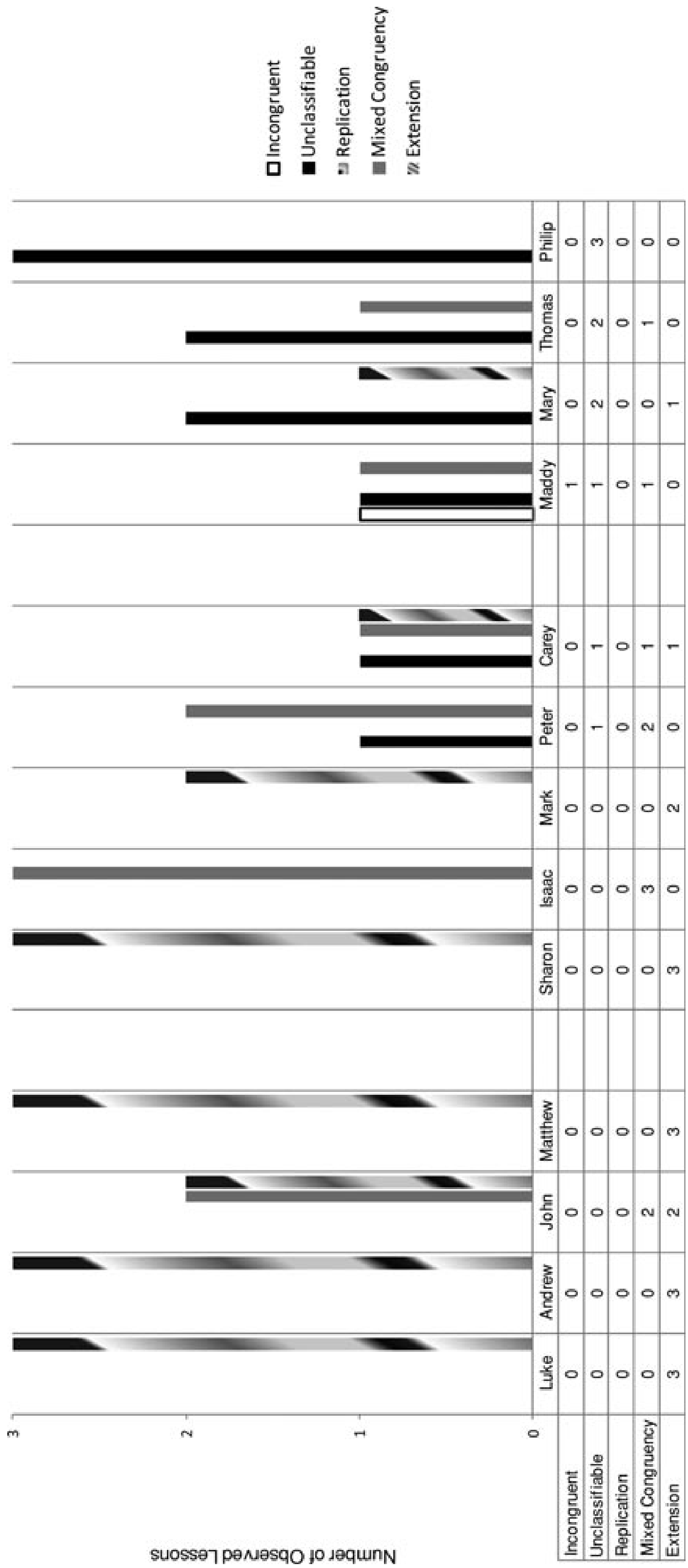
Artifacts. High NOS implementers' artifacts illustrated ample opportunities to implement NOS in the context of inquiry and/or the authentic work of scientists. These teachers' artifacts were rated "4" and/or "5" for NOS-COP items A and B, thus indicating their lessons provided abundant opportunities for addressing NOS if they wished to do so.

For the high NOS implementation teachers, the number of NOS-related artifacts ranged from 21% to 59% of the total number of artifacts submitted (Table 6). All high NOS implementers' artifacts included decontextualized NOS activities and lessons (e.g., black box activities, gestalt switches, brain teasers, decontextualized NOS discussion questions) reflective of those learned in their program's NOS course. Present in these decontextualized activities and lessons were questions that drew students' attention to, and made them think about, NOS ideas.

High NOS implementers were rated "4" and/or "5" for NOS-COP categories pertaining to the extent that their lesson artifacts accurately and effectively drew students' attention to, and made them think about, accurate NOS ideas in the context of science content and inquiry (NOS-COP categories D, F, and G). Any individual high NOS implementer's lesson artifacts (viewed as a collection) provide ample evidence that students' attention was drawn to and they were made to think about NOS ideas embedded in a lesson. Thus, for NOS-COP category I, each teacher's artifacts as a whole was rated "4" or "5."

All four high NOS implementers were rated "3" or higher for NOS-COP category E, but only Andrew received a 5. This was because Andrew's artifacts embedded questions that consistently required students to compare their classroom experiences to science in a manner that demanded deep reflection. For instance, in an inquiry-based density lab Andrew asked his students, "How is this lab experience like how real science works? How is this lab different than how real science works? How is this lab like the black box activity?"

Of the four high NOS implementers, Andrew and Luke scored a 4, and Matthew a 3, for the extent they scaffolded between decontextualized, moderately contextualized, and

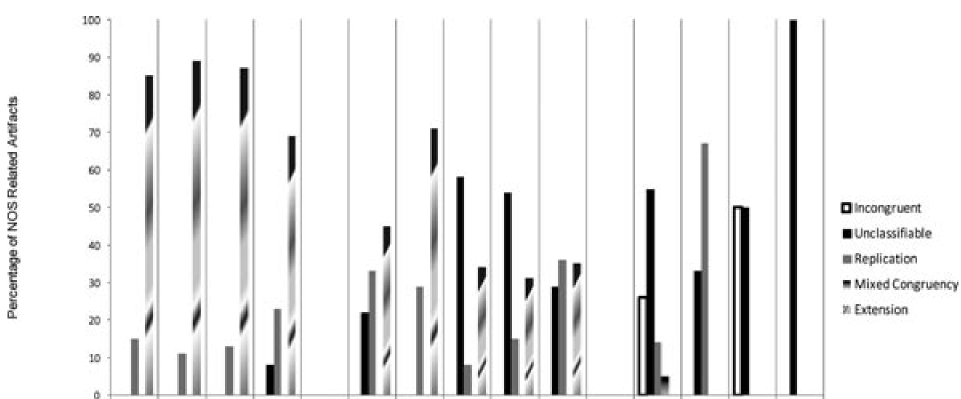


	Luke	Andrew	John	Matthew		Sharon	Isaac	Mark	Peter	Carey		Maddy	Mary	Thomas	Philip
Incongruent	0	0	0	0		0	0	0	0	0		1	0	0	0
Unclassifiable	0	0	0	0		0	0	0	1	1		1	2	2	3
Replication	0	0	0	0		0	0	0	0	0		0	0	0	0
Mixed Congruency	0	0	2	0		0	3	0	2	1		1	0	1	0
Extension	3	3	2	3		3	0	2	0	1		0	1	0	0

Figure 2. Extent that participants' observed lessons matched and/or extended beyond their science teacher education program NOS experiences.

TABLE 6
Study Participants' Lesson Artifacts and Analysis

NOS Implementers	Participant	Total Number of Artifacts	Total Number (Percentage) of NOS-Related Artifacts	NOS-COP A (Inquiry) Score	NOS-COP B (Scientists' Work) Score
High NOS implementers	Luke	81	48 (59)	5	5
	Andrew	23	8 (35)	5	4
	John	34	7 (21)	5	4
	Matthew	42	12 (29)	4	5
Medium NOS implementers	Sharon	26	9 (35)	4	2
	Isaac	22	7 (32)	4	2
	Mark	35	12 (34)	3	4
	Peter	38	15 (39)	3	4
	Carey	30	10 (33)	3	4
Low NOS implementers	Maddy	104	20 (19)	3	4
	Mary	49	7 (14)	3	2
	Thomas	36	4 (11)	2	1
	Philip	48	3 (6)	1	3



	Luke	Andrew	John	Matthew	Sharon	Isaac	Mark	Peter	Carey	Maddy	Mary	Thomas	Philip
Incongruent	0	0	0	0	0	0	0	0	0	26	0	50	0
Unclassifiable	0	0	0	8	22	0	58	54	29	55	33	50	100
Replication	15	11	13	23	33	29	8	15	36	14	67	0	0
Mixed Congruency	0	0	0	0	0	0	0	0	0	5	0	0	0
Extension	85	89	87	69	45	71	34	31	35	0	0	0	0

Figure 3. Extent that participants' lesson artifacts matched and/or extended beyond their science teacher education program NOS experiences.

highly contextualized NOS instructional experiences (NOS-COP category H). At best, these teachers' artifacts conveyed instances of scaffolding between decontexualized and moderately contextualized NOS experiences (e.g., how an inquiry experience was like an earlier black box experience), and/or sporadic attempts to scaffold between moderately contextualized and highly contextualized NOS examples.

High NOS implementers' classroom artifacts also indicated they taught NOS in a manner congruent with what was experienced in their science teacher education program. Figure 3 shows that 11%–23% of high implementers' NOS-related artifacts closely replicated NOS activities and instruction experienced in their teacher education program. 69%–89% of high NOS implementers' artifacts targeted NOS ideas and activities in novel and modified contexts not experienced in their teacher education program. It is noteworthy that only 8% of Matthew's NOS-related artifacts were unclassifiable due to a lack of NOS explicitness and none of the high NOS implementers' artifacts were incongruent with experiences in their teacher education program. Ample evidence supports the contention that high NOS implementers created and implemented explicit NOS artifacts appropriate for context of their classroom lessons.

Medium NOS Implementers

Lessons. The structure of medium NOS implementers' lessons provided fewer opportunities than high NOS implementers' lessons for drawing students' attention to and making them think about NOS ideas in the context of inquiry and/or historical/contemporary science examples (NOS-COP categories A and B). When lessons did afford ample opportunities to address NOS, medium implementers extensively did so in six of their lessons (as reflected in their receiving a rating of $\geq$4 for NOS-COP categories scales F or G).

Medium NOS implementers' portrayals of NOS were moderately to substantially accurate, receiving (NOS-COP category D) ratings of $\geq$ "4" for nine lessons and a "3" for the 10th lesson. Two of the medium NOS implementers' lessons contained major NOS inaccuracies and were rated "2." One lesson by Carey and another lesson by Peter were not rated for NOS-COP category D because those two lessons had no identifiable NOS themes.

Medium NOS implementers were less proficient than high implementers at requiring students to think about NOS ideas, even when students' attention was drawn to particular NOS ideas (NOS-COP category I). Only 5 of the 14 lessons conducted by medium implementers (collectively shared by Sharon and Carey) received NOS-COP category I rating of 4 or higher on this scale. With the exception of two lessons, all other medium NOS implementers' lessons received a rating of "2" or "3" on this scale, reflecting that students were only required to think superficially about NOS ideas that were drawn to their attention. One lesson by Carey and another lesson by Peter were not rated for NOS-COP category I because those two lessons had no identifiable NOS themes.

Like high NOS implementers, medium implementers struggled with attending students to how classroom lesson structures and/or their pedagogical practices accurately reflected or distorted NOS (NOS-COP category E), and with scaffolding between decontextualized, moderately contextualized, and highly contextualized NOS instructional experiences (NOS-COP category H). Only one lesson, conducted by Carey, possessed substantial scaffolding between decontextualized, moderately contextualized, and highly contextualized NOS instructional experiences (rated "3" on NOS-COP category H). The remaining lessons conducted by medium implementers lacked scaffolds between decontextualized, moderately contextualized, and highly contextualized NOS instructional experiences, and thus received NOS-COP category H scores $\leq$2.

Medium NOS implementers varied considerably in the extent their 14 lessons reflected NOS experiences in their science teacher education program. Figure 2 shows that six lessons conducted by three of the medium implementers went beyond NOS experiences in their teacher education program and addressed targeted NOS ideas and activities in novel and modified contexts. Six of the medium implementers' lessons demonstrated NOS instruction that was only partially congruent with what was experienced in the teacher education program. That is, while attempts to explicitly address NOS in novel and modified contexts were present in the lessons, NOS was taught with mixed accuracy and pedagogical effectiveness. Only two lessons conducted by Peter and Carey lacked any discernible NOS instruction and were therefore unclassifiable in the extent that the lesson reflected NOS experiences in their teacher education program. None of the medium NOS implementers' lessons were incongruent with what was experienced in their science teacher education program.

Artifacts. The percentage of NOS-related artifacts for NOS medium implementers compared favorably with those of NOS high implementers (Table 6). However, the quality of those NOS-related artifacts was such that far fewer opportunities existed for accurately and explicitly addressing NOS. Thus, medium NOS implementers consistently scored "3" and/or "4" for NOS-COP categories A and B.

Much like high NOS implementers, medium implementers' NOS-related artifacts were largely accurate (rated ≥4 on NOS-COP category D). Each medium NOS implementer's artifacts contained evidence of introductory decontextualized NOS activities and lessons (e.g., black box activities, gestalt switches, decontextualized discussions on NOS ideas) that closely resembled those demonstrated in their Nature of Science in Science Education course. Furthermore, medium implementers retrospectively referred to these activities and lessons through questions in subsequent artifacts. This would require students to think about a NOS idea and was a significant reason these teachers scored 3 or higher for requiring students to reflect on identified NOS themes (NOS-COP scale I).

Not only did the quality of medium implementers' NOS-related artifacts present far fewer opportunities for accurately and explicitly addressing NOS, but the medium implementers were not as adept as high implementers at addressing NOS opportunities that did exist in their artifacts. Medium NOS implementers' artifacts scored "3" or "4" on how well they addressed NOS consistently, explicitly, and reflectively in the context of teaching science content or teaching science through inquiry (NOS-COP categories F and G).

Only Isaac's and Sharon's artifacts illustrated attempts at drawing their students' attention to, and having them think about, how classroom instructional structures and pedagogical practices accurately reflect or distort NOS (rated ≥3 on NOS-COP category E). Furthermore, only Isaac's artifacts provided evidence of scaffolding, albeit inconsistent, between decontextualized, moderately contextualized, and highly contextualized NOS instructional experiences (rated 3 on NOS-COP category H).

Compared to high NOS implementers' artifacts, medium NOS implementers' artifacts varied considerably in the extent they reflected experiences in their science teacher education program. Figure 3 shows that 8%–36% of medium implementers' NOS-related artifacts closely replicated experiences in their teacher education program. 31%–71% of medium NOS implementers' artifacts went beyond NOS experiences in their teacher education program and effectively addressed targeted NOS ideas and activities in novel and modified contexts. None of the medium NOS implementers' artifacts demonstrated incongruence with NOS experiences in their teacher education program. While this is encouraging, up to 58% of the medium NOS implementers' artifacts were unclassifiable due to no explicit links to NOS.

Low NOS Implementers

Lessons. Low NOS implementers' lessons afforded far fewer opportunities for drawing students' attention to and making them think about NOS ideas (NOS-COP categories A and B). Of this group's 12 observed lessons, only half were rated ≥3 for NOS-COP categories A or B. Six lessons were structured in a manner (e.g., presenting final form science and/or cookbook activities) that would make addressing NOS quite difficult (rated "1" and/or "2" for NOS-COP categories A and B).

In 5 of the 12 observed lessons, including 3 of the 6 lessons just mentioned above, low NOS implementers made no attempts to draw their students' attention to NOS. Consequently, these teachers were rated "N/A" for NOS-COP category D and "1" for NOS-COP categories E through I. Seven of the twelve lessons conducted by low NOS implementers had detectable efforts at drawing students' attention to NOS, but only one lesson did so extensively (rated "4" on NOS-COP category G). Three of these seven lessons moderately addressed NOS (rated "3" on NOS-COP categories F and G), whereas the remaining three lessons earned NOS-COP categories ratings <3. Only two of the seven lessons having detectable efforts to teach NOS required students to reflect upon identified NOS themes at a moderate level (rated 3 on NOS-COP category I). In the other five lessons, low NOS implementers either neglected, or had significant trouble, asking questions that would make their students think about NOS ideas (reflected in their being rated ≤ 2 on NOS-COP category I).

When low NOS implementers did address NOS, the portrayals often contained inaccuracies. Only two lessons conducted by low NOS implementers portrayed NOS with acceptable accuracy (rated ≥ 3: NOS-COP category D). Of the low implementation teachers, only one lesson satisfactorily had students consider how a lesson structure and/or the teacher's pedagogical practices reflected or distorted NOS (rated "3" for NOS-COP category E). All other lessons by low NOS implementers were rated ≤ 2 for this category. All low NOS implementers' lessons lacked evidence of scaffolding between decontextualized, moderately contextualized, and highly contextualized NOS instructional experiences (NOS-COP category H) with 10 observed lessons rated "1" and the remaining two lessons rated "2."

Low implementers struggled to implement NOS in a manner that reflected or went beyond what was experienced in their science teacher education program. Eight of the twelve low NOS implementers' lessons were unclassifiable regarding the extent they reflected or moved beyond experiences in their teacher education program. These lessons either completely lacked NOS instruction or NOS was portrayed at barely discernible levels. Moreover, three low implementers' lessons either portrayed NOS in a manner incongruent or of mixed congruency with that experienced in their teacher education program. Of the low implementers, only one lesson went beyond experiences in the teacher education program and addressed targeted NOS ideas and activities in a novel and modified context.

Artifacts. Compared to high and medium NOS implementers, many of the low NOS implementers' lesson artifacts afforded far fewer opportunities to raise NOS ideas. The percentage of NOS-related artifacts for NOS low implementers ranged from 6–19. Most low NOS implementers' artifacts did not represent reform-based practices in science education, instead emphasizing the teaching of science content in a highly directive manner that did not encourage students to be mentally engaged. When low NOS implementers' lesson artifacts made reference to NOS, they often were inaccurate and contradictory. Thus, none of the low implementers received a rating higher than "2" on their NOS artifacts for accuracy (NOS-COP category D).

Two low implementers' artifacts indicated the use of decontextualized activities (e.g., black box activities and/or gestalt switches) early in the school year. The value of decontextualized NOS activities early in the school year to introduce NOS reflected what was promoted in their preservice program's NOS course. Other lesson artifacts indicated they assessed students on these ideas. These two teachers were rated "3" for NOS-COP category I because this sort of NOS instruction was present at times, but not common.

Evidence of students' attention being drawn to NOS ideas within the context of science content and inquiry lesson instruction was rarely apparent in lesson artifacts collected from low implementers (NOS-COP category F). None of the low NOS implementers' artifacts provided evidence of scaffolding along the NOS context continuum (NOS-COP category E).

Compared to high and medium NOS implementers, low NOS implementers' artifacts rarely extended beyond that which was experienced in their science teacher education program. Figure 3 shows that at best 14%–67% of Maddy's and Mary's NOS-related artifacts closely replicated experiences in their teacher education program. Also, 5% of Maddy's NOS-related artifacts were of mixed congruency with NOS instruction experienced in the teacher education program. Conversely, 33%–100% of the low NOS implementers' artifacts were unclassifiable because any NOS was implicit. Moreover, 26%–50% of Maddy's and Thomas' NOS-related artifacts were incongruent (largely because of explicit inaccuracies about how science works) with NOS experiences in the teacher education program.

Summary of Findings

- Twelve of the 13 study participants implemented NOS instruction to at least some extent reflective of what was taught and modeled in their science teacher education program (Figures 2 and 3). Four of these 12 did so at a high level, five did so at a medium level, and three study participants categorized as low implementers attempted to teach NOS either decontextually or contextually. Two of these low implementers taught NOS decontextually early in the school year and periodically drew their students' attention to NOS and had them think about identified NOS issues (Table 5). One of these low implementers, and one of the low implementers that did not utilize decontextualized NOS activities, attempted to teach NOS in the context of science content. However, their efforts contained substantial inaccuracies, pedagogical problems, and no scaffolding to other instances of NOS instruction. The remaining study participant did not accurately or effectively teach NOS in any discernible manner.
- All high NOS implementers addressed targeted NOS ideas and activities in novel and modified contexts that went beyond NOS experiences in their science teacher education program (Figures 2 and 3). Medium implementers varied considerably in the extent their instruction reflected their teacher education program's promotion of NOS instruction. Only one low implementer's lesson addressed NOS in a novel and modified context not experienced in their teacher education program. All other attempts made by low implementers were either replications of NOS activities from their preservice program, unclassifiable due to implicitness of NOS, or substantially inconsistent with NOS instruction experienced in their teacher education program.
- No relationship existed between study participants' years of teaching experience and NOS implementation level (Tables 2 and 5).
- Six of the 13 teachers' summative views of NOS were informed, six were transitional, and one was not classifiable (Tables 3–5). Teachers with informed and transitional NOS understanding were found at all three NOS implementation levels.
- The extent that study participants' lessons included teaching science through inquiry (NOS-COP category A) and/or included historical/contemporary science examples (NOS-COP category B) varied considerably. Observed lessons (Figure 1) and lesson artifacts (Table 6) illustrate that instances of teaching science through inquiry and/or inclusion of historical/contemporary science examples was highest for high NOS implementers, lower for medium NOS implementers, and much lower for low NOS implementers.

- Study participants were more adept at teaching NOS in the context of teaching science through inquiry than when presenting science content in a more directive fashion.
- Study participants struggled to scaffold between decontextualized, moderately contextualized, and highly contextualized NOS instructional experiences.
- Study participants infrequently drew their students' attention to, and had them think about, how particular classroom instructional practices (e.g., cookbook laboratories vs. inquiry laboratories, common textbook readings vs. accurate historical accounts regarding the development of ideas) and/or their pedagogical practices (e.g., questioning students vs. simply telling students answers) distorted NOS.

DISCUSSION AND IMPLICATIONS

Study Overview

The purpose of this study was to determine the NOS implementation practices of teachers who completed an extensive and demanding secondary science teacher education program. Unlike many prior studies that investigated teachers' NOS instructional practices during student teaching or immediately after completing a teacher education program, teachers in the study reported here were in their second to fifth year of teaching after having completed their preservice science teacher education program (or in the case of John, his second year after having completed his M.S. program). All teachers in our study thus had time away from the program to autonomously understand and develop their general, science content, and NOS pedagogical practices. Importantly, these teachers were not encouraged by their schools to teach NOS and all teachers faced constraints in their efforts to teach NOS. Thus, the NOS teaching practices reported in the Findings section were very likely influenced by what these teachers experienced in their teacher education program.

Study Participants' Teaching Experience and NOS Understanding

The NOS implementation level of participants in our study is not associated with their years of teaching experience. High implementers' teaching experience ranged from 3 to 14 years (although John was in his second year of teaching after having completed the M.S. program). Medium implementers' teaching experience ranged from 2 to 5 years, and low implementers' teaching experience ranged from 3 to 5 years (Table 2). This does not mean that experience teaching NOS is unimportant, only that years of experience do not necessarily result in medium and high NOS implementation.

Congruent with previous NOS research and literature (Abd-El-Khalick & Lederman, 2000; Brickhouse, 1990; Duschl & Wright, 1989; Hodson, 1993; Lederman, 1992, 2007; McComas, 1998), our study participants' NOS understanding was not necessarily translated into NOS instructional practice. While all high NOS implementers in our study were categorized as possessing informed NOS content understanding, one medium implementer and one low implementer also possessed informed NOS content understanding. None of our study participants possessed lower than a transitional understanding of NOS (Table 4). The NOS understanding possessed by most teachers in this study appeared to be higher than what was translated to practice in their lessons and artifacts. However, teachers' attention to particular NOS constructs was limited by their understanding of those constructs. For instance, teachers' language in observed lessons and artifacts conveyed that science ideas were discovered and lacked attention to the inventive character of scientific knowledge. The language that teachers use plays an important role in students' NOS understanding (Zeidler & Lederman, 1989). Thus, consistent with prior studies, our findings support the contention that teachers' understanding of NOS is a necessary, but insufficient condition for accurate and effective NOS instruction.

Many researchers (Abd-El-Khalick & Ackerson, 2004; Lederman, 1999, 2007; Schwartz & Lederman, 2002; among others) have called for deeper inquiry into factors beyond teachers' NOS understanding that account for NOS implementation. Below we discuss a few factors that appear to impact our study participants' NOS implementation. (See Herman et al. (2011) for a more comprehensive analysis of factors impacting study participants' NOS implementation.)

Study Participants' Science Teacher Education Program

Two teachers in this study completed the undergraduate version of the program, and 10 completed the graduate version of the program (Table 1). The 13th study participant, a veteran teacher, completed the graduate M.S. program that included the Nature of Science and Science Education course and the Advanced Pedagogy in Science Education course. The undergraduate students in this program complete six science education specific courses (13 semester hour credits) prior to student teaching. Graduate licensure (MAT) students complete seven science education–specific courses (16 semester hour credits) in addition to student teaching. The contact hours for these courses exceeded what is typically associated with the credits hours earned. Ten of these study participants *chose* to complete an optional 3 semester hour credit course in addition to this (a common occurrence among students in this program). Clearly, the science education component of this preservice experience far exceeds that required in most preservice secondary science teacher education programs. So while the number of study participants who addressed NOS, and the extent that they did so, is impressive, the science teacher education program they experienced is far from typical.

The required Nature of Science and Science Education course is undeniably important in study participants' NOS instructional practices. However, more is at play here. The sequence of secondary science methods courses repeatedly refer to the NOS course, and explicit connections to NOS are made throughout the methods courses in helping teachers understand

- the difficulties learners have in truly understanding science (e.g., the counterintuitive nature of many science ideas, and the epistemological and ontological assumptions underlying science that differ from views held by students),
- the implications of NOS for effective science content instruction, and
- what teaching science *through* and *as* inquiry entails.

The optional Restructuring Science Activities course that most students in the program, including 10 of the 13 participants in this study, complete also seeks to promote effective NOS instructional practices. This course is offered to preservice teachers after they have completed the NOS course and the series of secondary science methods courses. Students in this course first experience several inquiry science activities that require mental engagement and decision making, and effectively promote many science education goals including understanding NOS. They then modify activities they have located so that the activities will do the same. These modified activities must include questions that draw students' attention to, and make them think about, targeted NOS ideas. Students are required to submit one of their modified activities to the state science teacher journal, and most of these have been published (http://www.iacad.org/istj/issues.html). All of the participants who took this course conveyed it was a crucial experience in the program because it provided additional concrete examples of how to effectively incorporate NOS instruction in the context of science activities, and it forced students to apply their understanding of NOS and effective NOS pedagogy in their own efforts to modify science activities. These sorts of activities were also modeled in the NOS course and in the methods courses, but study participants clearly valued a course at the end of the program that consolidated much of what they had experienced throughout the program. Reflecting the extensive time required for deep conceptual change to occur, these reoccurring experiences likely play a key role in developing among teachers the combination of NOS content knowledge, NOS pedagogical knowledge, and PCK needed for effective NOS instruction (Clough, 2006; Lederman, 2007; Schwartz & Lederman, 2002).

We acknowledge that factors beyond study participants' science teacher education program (e.g., development of NOS–PCK through practice and reflection, experiences with NOS materials) may have contributed to their NOS teaching practices. However, study participants' NOS experiences in their science teacher program provided an important lens to recognize, value, and benefit from any exposure to NOS learning and teaching opportunities that occurred beyond the confines of their teacher education program. Thus the impact of any additional factors on study participants' NOS teaching practices does not detract from the impact of the science teacher education program that study participants experienced.

The study reported here, like that of prior research by Abd-El-Khalick et al. (1998) and Bell et al. (2000), followed concerted efforts in a teacher education program to promote accurate and effective NOS instructional practices. These studies make clear that promoting accurate, effective, and consistent NOS instructional practices among teachers is not easily accomplished. Given the results of these intense efforts to promote effective NOS instructional practices, more typical teacher education programs that require a single methods course (general or science education specific) are unlikely to result in science teachers who are even remotely prepared to implement highly effective NOS instructional practices.

Afforded Opportunities

The extent that our study participants implemented NOS instruction was associated with the extent that their observed lessons and lesson artifacts contained inquiry activities and/or information regarding authentic research (historical or contemporary) efforts by scientists (Figure 1 and Table 6). Study participants appeared far less capable of capitalizing on NOS instructional opportunities when they were in the midst of delivering science content or leading class discussions targeting science content.

Even when teachers in our study had not consciously planned beforehand to address NOS, such lesson structures (i.e., inquiry activities and/or stories about science and scientists) *afforded opportunities* for raising NOS issues. Throughout this paper, we have purposely used this phrase to convey this important point. That is, while purposely planning for NOS instruction is undeniably an important factor for effectively addressing NOS, just as important is having lesson structures (e.g., teaching science through inquiry and/or including historical/contemporary episodes of science in action) from which to draw out NOS ideas in the act of teaching. Our high and medium NOS implementation teachers seized on opportunities to address NOS, both in situations they had purposely created to address NOS, but also in lessons (i.e., inquiry activities and use of historical and contemporary examples of authentic research by scientists) where they had not intended to address NOS.

The Nature of Science and Science Education course, methods courses, and Restructuring Science Activities course that study participants completed forcefully taught that while NOS should be a planned instructional objective, teachers who deeply understand NOS and NOS pedagogy also capitalize on unplanned opportunities to teach NOS in the act of effective science teaching more broadly. The above science education courses press teachers to identify in common classroom activities (e.g., laboratory activities, readings, multimedia) NOS ideas that could be drawn out for student attention and thinking, and this likely assists in planning effective NOS lessons but also in capitalizing on unplanned NOS opportunities while in the act of teaching.

In classroom observations of higher NOS implementers, many instances of NOS instruction occurred that appeared unplanned, reactionary, or "in the heat of the moment." This occurred when a teacher recognized the opportunity to teach NOS based on students' remarks, the characteristics of an activity (typically an inquiry activity), or a reading or video that addressed in some way the work of scientists. For instance, while John was discussing science content related to the law of falling bodies, a student expressed that a theory is prerequisite to a law and that with enough evidence actually becomes a law. In response, John redirected the discussion to address this misconception by questioning the class about how their prior classroom activities dealing with falling bodies helped them conceptualize not only the invariable relationships and patterns in nature (laws) but also unifying explanations for those invariable relationships and patterns in nature (theories). John later stated he did not anticipate that NOS misconception and admitted it caught him off guard.

During unstructured pre- and postlesson interviews, all of the high NOS implementers expressed that they are able "see" opportunities for NOS instruction as they came up. While they did sometimes purposely plan for and create NOS instructional opportunities, much of their decision making to address NOS was made in the act of teaching—drawing from their NOS content and NOS pedagogy knowledge to seize on lesson opportunities (e.g., when teaching science through inquiry, when a student raised a particular idea, or when addressing the authentic work of scientists). This is nicely illustrated in the following comment from Matthew:

> I knew you wanted to [teach the NOS] throughout the year, but I thought you had to set aside a specific time to address the nature of science-like a specific thing you are going to do. But everything we are doing there is nature of science stuff you can pull out. The more comfortable I am with knowing [students'] conceptions the more I am able to go into whatever nature of science ideas surround whatever we are talking about.

A similar sentiment was conveyed by Luke, who stated,

> When I am teaching I often say to myself things like "Oh, there are nature of science ideas I could have taught there." However, at the same time there is earth science content I have to teach.... The nature of science to me is more important than any other content the students will learn. I do want to teach them content because it is a part of being scientifically literate, but even more important is how and why scientists do their jobs, and the philosophical assumptions they have.

Andrew also conveyed he recognizes unplanned opportunities to draw students' attention to implicit NOS ideas present in inquiry-based activities. This was clear when he explained that after first helping students determine the density of ball bearings and small pieces of Styrofoam, he recognized many implicit NOS ideas present in the activity and picked which NOS ideas to draw students' attention to. Andrew explained how this was done by stating,

> Eventually they came to the idea that it [the density of smaller pieces of substances] was the same [as larger pieces of the same substance] after much help and talk and retesting and thinking. *What nature of science ideas can you pull from that? Many. The one that I picked was consensus.* I asked, "But why can't we vote? Why would that be an issue? I

> mean, we don't have any evidence to back it up [in a vote]. We are just putting our opinion in for it. Well, how does that work in science if we did that? It really wouldn't. You know they wouldn't do that." So I draw attention to what scientists actually do and then model for them: "This is what we need to do." I also ask, "And why would it be useful that we have to use evidence to figure it out? Why is that a different type of communication with people than voting?"

We are not marginalizing the importance of deliberately thinking of NOS as a content objective or purposely planning NOS instruction. The higher NOS implementers in our study clearly valued NOS as a learning goal for students and did at times plan for such instruction. But *because their lessons had structural features that afforded ample opportunities* for accurately addressing NOS (i.e., inquiry lessons and/or addressing scientists' work), in addition to sometimes deliberately planning for NOS instruction, they also recognized spontaneous opportunities to teach NOS, and when they deemed appropriate, capitalized on those opportunities.

One important implication of this study is that accurately and effectively teaching NOS is linked to other efforts to improve science teaching (e.g., teaching science through inquiry, including historical and contemporary stories of authentic science, asking effective questions that draw out students' thinking and engage them in meaningful reflection). We maintain that promoting accurate and effective NOS instruction should focus both on purposely planning for NOS instruction and also on helping teachers quickly identify NOS issues embedded in activities, readings, and other lesson materials. Doing so will assist teachers in identifying NOS issues in the act of teaching and seize on such opportunities when a teacher deems appropriate. And in accomplishing this, the concern expressed by Luke (and likely widely held) that NOS instruction means teachers must "set aside a specific time to address the nature of science—like a specific thing you are going to do" is mitigated.

Our empirical findings (particularly findings from NOS-COP categories A and B) bolster the case previously put forward (Clough, 1997, 2006; Lederman, 2006; Matthews, 1994, and many others) that inquiry science teaching practices and incorporating historical and contemporary stories that accurately portray the work and lives of scientists form a foundation for, but do not ensure, effective NOS instructional practices. But our findings go further. The lessons of the four low NOS implementers in our study were such that they *afforded far fewer opportunities* for addressing NOS. Two of the low implementers did plan for and carry out decontextualized NOS activities at the beginning of the school year, but the structure of their lessons thereafter did not present ample opportunities for accurately addressing NOS. Thus, effective NOS instructional practices are to some extent intricately tied to other pedagogical decisions and behaviors.

Study Participants' Common Struggles

Regardless of a teacher's commitment to accurately and effectively address NOS, not all lessons will be well suited for accurately modeling aspects of NOS. The science education course work that study participants completed acknowledged this and encouraged teachers, when appropriate, to ask students how a lesson may have departed from how authentic science is done. For example, for cognitive or safety reasons, students may need to follow a step-by-step laboratory procedure, or a teacher may spend considerable time presenting what Duschl (1990) calls "final-form science." In these instances, students' attention can be drawn to features of the lesson that accurately or wrongly reflect authentic science. Teachers in our study often asked students to consider how a lesson accurately reflected

NOS, but rarely drew students' attention to and had them think about how a lesson may have distorted NOS.

All teachers in our study also struggled to ask questions that linked decontextualized, moderately contextualized, and highly contextualized NOS classroom experiences. They did ask such questions at times, but not as ubiquitously as the science education courses in their teacher education program promoted. As Clough (2006, p. 487) noted, "Attention to the decontextualized/contextualized continuum and its potentially critical role in NOS instruction, unfortunately, demands a much deeper understanding of the NOS than is common among classroom teachers." Perhaps only teachers with advanced understanding of science content, NOS, how people learn, effective pedagogy, and both science content PCK and NOS PCK are able to consciously and effectively teach NOS in varied science contexts and create explicit scaffolds between these experiences.

That study participants struggled to scaffold back and forth between decontextualized, moderately contextualized, and highly contextualized NOS classroom experiences, and their earlier noted difficulties capitalizing on NOS instructional opportunities when they were in the midst of teaching science content or leading class discussions targeting science content, has implications for science teacher education programs and further research. The NOS course that study participants completed did address and model these neglected NOS pedagogical practices. Moreover, assignments in the NOS course required students to exhibit this understanding, as did other aspects of the science teacher education program. However, clearly more is needed.

Perhaps these difficult NOS pedagogical practices demand that science teacher education programs include more than one NOS course, just as more than one science methods course is needed to prepare effective science teachers (Roehrig & Luft, 2006). Student teacher supervision that promotes these NOS pedagogical practices would also help. University supervisors in the science teacher education program that study participants completed come from the rank of former school principals, and their understanding of NOS and NOS pedagogy was not such that they could assist in further developing important NOS pedagogical practices. Perhaps teachers need curriculum resources that assist them in addressing NOS in the context of the science content they teach. This was a key rationale behind the *Story Behind the Science* (http://www.storybehindthescience.org) postsecondary project (Clough, 2011b), and efforts are underway to create the same kinds of NOS resources appropriate for secondary school science. Finally, support through the induction years of teaching would assist in implementing effective NOS pedagogy. However, such support will almost assuredly have to come from science teacher education programs. Every participant in the study reported here commented on the lack of colleague and administrative support for, or institutional constraints that worked against emphasizing NOS in their science teaching. Each of these areas are deserving of further research.

NOS-COP

The NOS-COP instrument we created and employed in this study is a useful tool for research investigating the NOS implementation practices of science teachers. The instrument provides a means for standardizing classroom observations regarding NOS classroom implementation practices and adds needed nuances and clarity to such research. For instance, in reviewing many prior studies addressing teachers' NOS implementation practices, much of what those teachers did and did not do is unclear. For this reason, comparing the outcomes of studies investigating teachers' NOS implementation practices is at best haphazard without a clear and transparent NOS classroom research protocol and scoring guide. The NOS-COP instrument we put forward here is designed to advance that clarity and transparency in NOS implementation research. Additional categories may be added at researchers' discretion, but NOS-COP categories A through I and illustrative vignettes reflect the literature regarding instruction that promotes a deep and robust understanding of NOS. Thus, we maintain that these categories and vignettes are essential for providing a thorough and transparent picture of NOS implementation practices, one that permits legitimate comparisons between studies regarding teachers' NOS instructional practices.

The NOS-COP we developed purposely sets a high bar for NOS instruction. High implementation reflects the very best of what we should expect of science teachers (i.e., accurate and consistent NOS instruction that draws students' attention to important NOS ideas in a variety of contexts and has students think deeply about those NOS issues). The medium implementation category characterizes NOS instructional practices far exceeding what is commonly found among science teachers, but it falls short of desired NOS implementation practices. The low implementation category characterizes practices that range from no discernable NOS instructional practices to those that are problematic in ways that are unlikely to promote student development of a deep and robust NOS understanding.

Thus, that 4 of the 13 study participants implemented NOS at a high level and 5 implemented NOS at a medium level is all the more impressive. Three of the four low implementers also taught NOS, but not in a manner that would promote a deep and robust NOS understanding among their students. Again, the NOS-COP instrument provides a research protocol that is useful for clarifying and making transparent the categorization and reporting of NOS instructional practices.

Having students understand NOS has been a longstanding science education goal. Yet, little evidence exists indicating science teachers implement accurate and effective NOS instruction. Thus, the significant and pervasive NOS misconceptions held by students at all levels is hardly surprising. Preservice science teacher education programs bear much of the responsibility for this deplorable situation, as few require any significant attention to NOS content and pedagogy in their preservice programs (Backhus & Thompson, 2006). Lederman (2006), lamenting the lack of progress in improving instruction regarding science more generally, and NOS and inquiry more specifically, writes,

> Although the words of various reforms are different, the message remains quite familiar. Just as familiar is the lack of progress toward the all too familiar goals of reform efforts. . . . There is not, and there has not been, a concerted professional development effort to clearly communicate, first, what is meant by "NOS" and scientific inquiry and second, how a functional understanding of these valued aspects of science can be communicated to K-12 students. (pp. 301, 302)

The study presented here illustrates that an extensive and demanding secondary science teacher education program can promote among its graduates significant attention to what research makes clear is essential for accurate and effective NOS instruction. But science teacher education programs like the one described in this study are clearly the exception, not the rule. Effective science teaching is a highly complex act, and learning how to effectively teach NOS and scientific inquiry, as Lederman accurately states, requires "concerted professional development." What remains to be seen is whether decisions regarding education policy will acknowledge that much *is* known about preparing highly effective science teachers and support the concerted professional development that prospective science teachers need.

APPENDIX A: NATURE OF SCIENCE CLASSROOM OBSERVATION AND ARTIFACT PROTOCOL (NOS-COP)

Category		None Great Extent	D/K[a]	N/A[b]
Extent that the lesson structure and artifacts have clear opportunities for accurately and explicitly addressing NOS				
A	Science is taught through inquiry.	1 2 3 4 5	6	7
B	Historical/contemporary accurate examples of science and/or scientists are incorporated in the lesson.	1 2 3 4 5	6	7
C	Other (please specify)	1 2 3 4 5	6	7
Extent to which the instructor and/or lesson structure and artifacts explicitly and reflectively addressed NOS				
D	NOS ideas addressed are accurate	1 2 3 4 5	6	7
E	Students' attention is explicitly and reflectively drawn to how classroom instructional practices reflect or distort NOS.	1 2 3 4 5	6	7
F	Students' attention is explicitly and reflectively drawn to NOS in the context of science content being taught.	1 2 3 4 5	6	7
G	Students' attention is explicitly and reflectively drawn to NOS ideas implicit in inquiry activities.	1 2 3 4 5	6	7
H	NOS ideas are explicitly and reflectively scaffolded back and forth along the decontextualized to highly contextualized NOS Context Continuum.	1 2 3 4 5	6	7
I	Students are required to reflect on explicitly identified NOS ideas in the lesson.	1 2 3 4 5	6	7

[a]Don't know.
[b]Not applicable.

NOS Implementation Synthesis Rating

NOS Implementation Synthesis Rating				
1	2	3	4	5
Not at all reflective of NOS instruction best practices in science education.				Highly reflective of NOS instruction best practices in science education.

Extent to Which the Lesson Structure and Artifacts Have Clear Opportunities for Accurately and Explicitly Addressing NOS

Score	Observations	Artifacts
A. Science is taught through inquiry		
5	Evident elements of inquiry are consistent in the lesson (e.g., learning cycle, interactive discussions that overtly draw on previous activities and scaffold into new ones).	Inquiry consistent in artifacts. (e.g., inquiry activities coupled with open ended questions).
3	Approximately equal amounts inquiry and traditional instruction (e.g., lecture before inquiry activity, students being told results during inquiry activity, interactive discussions that tacitly draw on previous activities).	Approximately equal amounts inquiry and traditional instruction (e.g., fact recall) evident.
1	No inquiry evident in lesson (e.g., lecture with no interaction with students).	No inquiry evident (e.g., artifacts primarily consist of fact recall tests and assignments).
B. Historical/contemporary accurate examples of science and/or scientists are incorporated in the lesson		
5	Historical and/or contemporary example(s) are an integral part of the lesson, and are meaningful, highly accurate, and relevant to lesson.	Historical and/or contemporary example(s) are consistently used, an integral part of the artifacts, and are meaningful, and accurate.
3	Historical and/or contemporary example(s) are referred to in the lesson. May be shallow, inaccurate, and/or irrelevant to the lesson.	Historical and/or contemporary example(s) are present in the artifacts. May be shallow, inaccurate, and/or irrelevant to other artifacts.
1	No historical or contemporary examples present.	No historical or contemporary examples present.
C. Other		

Extent to Which the Instructor and/or Lesson Structure/Artifacts Explicitly and Reflectively Addressed NOS

Score	Observations	Artifacts
D. NOS ideas addressed are accurate		
5	NOS ideas are highly and consistently accurate. *Exemplar*: "How do scientists go about figuring out information, or an argument they are having? Why can't we just vote in science?" (Andrew)	NOS ideas are highly and consistently accurate. *Exemplar*: "In what sense are scientific laws and theories different types of knowledge? In what sense are they related?" (John, A3)
3	Minor inaccuracies present.	Minor inaccuracies present.

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	Exemplar: "If you lie you will not do science again as science will not tolerate lying. Science relies on truthful evidence and we rely on these numbers as evidence in this class." (Peter)	*Exemplar*: "Researchers in the late 1800's discovered that something smaller than bacteria could cause disease." (Peter, A1)
1	Consistent and/or major inaccuracies present. *Exemplar*: "Robert Hooke was doing this experiment of cork." "Many people won't buy it unless there is proof." (Maddy)	Consistent and/or major inaccuracies present. *Exemplar*: "Why is it extremely important that scientists do not allow past experiences, other people's ideas or what they want to be the answer to influence their observations?" (Maddy, A5)
E. Students' attention is explicitly and reflectively drawn to how classroom instructional practices reflect or distort NOS		
5	Attention drawn explicitly, reflectively and deeply. *Exemplar*: "How is a law different than a theory? Think of how when we observed falling bodies and how they fit within those patterns. How did we attempt to explain those patterns?" (John)	Attention drawn consistently, explicitly, reflectively and deeply. *Exemplar*: "To what extent do you think that the way we progressed through these demonstrations modeled authentic scientific activity?" (John, A2)
3	Attention is limited in explicitness, reflectivity, and/or depth. *Exemplar*: In response to student mistakes in an inquiry based lab: "Having an issue with the validity of data is like an issue in science." (Peter)	Attention is limited in explicitness, reflectivity, depth, and/or consistency. *Exemplar*: "What previous knowledge or experiences did you think of while writing your story? How might previous knowledge help and how might it hinder an investigation?" (Sharon, A4)
1	Nonexistent	Nonexistent
F. Students' attention is explicitly and reflectively drawn to NOS in the context of science content being taught		
5	Attention drawn explicitly, reflectively and deeply. *Exemplar*: In relation to glacially carved valleys: "Why should we not use supernatural ideas such as Paul Bunyan to explain the natural world?" (Luke)	Attention drawn consistently, explicitly, reflectively and deeply. *Exemplar*: "Lyell is studying nature. How is his work different from the idea that scientists do all of their work in a lab? In what way is his work similar?" (Luke, A1)
3	Attention is limited in explicitness, reflectivity, and/or depth. *Exemplar*: Stating: "Schleiden and Schwann were sitting having dinner and then decided all things were made of cells	Attention is limited in explicitness, reflectivity, depth, and/or consistency. *Exemplar*: Asking: "What did John Bennet Lawes create, and what effects has it had on the world?" with no focus on a

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	and they made the cell theory" with no questions afterwards (Maddy)	specific NOS theme (Carey, A4)
1	Nonexistent	Nonexistent
G. Students' attention was explicitly and reflectively drawn to NOS ideas implicit in inquiry activities		
5	Attention drawn explicitly, reflectively and deeply. *Exemplar*: During an inquiry activity with dichotomous keys: "Think about the dichotomous keys in relation to plants and animals. To what extent do you think they were invented or discovered?" (Luke)	Attention drawn consistently, explicitly, reflectively and deeply. *Exemplar*: "How does this activity relate to the scientists we have learned about in this case study? What roadblocks did you hit while creating your thermometer? How do you know your thermometer really works? How might a scientist have figured out if their tool actually worked?" (Matthew, A11)
3	Attention is limited in explicitness, reflectivity, and/or depth. *Exemplar*: After lecturing on Mendeleev using patterns to sort elements asking in an inquiry based periodic table activity: "What characteristics did you use for sorting the cards? What patterns appear in your arrangements?" (Matthew)	Attention may exclude explicitness, reflectivity, depth, or consistency. *Exemplar*: Only explicitly addressing NOS superficially in initial decontextualized activities and then not embedding NOS in later contextualized activities, e.g., Asking: "Why are models like this used in science?" solely on an introductory tube lab (Mary, A4).
1	Nonexistent	Nonexistent
H. NOS ideas were explicitly and reflectively scaffolded back and forth along the decontextualized to highly contextualized NOS instructional continuum		
5	Scaffolds constructed explicitly, reflectively and deeply along entire continuum. *Examplar*: "To what extent do our investigations with falling bodies relate to the tube activity? How did you have to use imagination and creativity in both of these investigations? In what ways was this like how Galileo used creativity and imagination?" (None recorded)	Scaffolds consistently constructed explicitly, reflectively and deeply along entire continuum. *Exemplar*: "In relation to quote from Einstein on studying closed systems: Using your own words paraphrase what Einstein is saying. In what ways is what Einstein saying relate to the tube activity? Give other examples from science that illustrate this idea." (Isaac, A4)
3	Scaffolds may be superficial or incomplete (e.g., decontextualixed to moderately contextualized). *Exemplar*: Asking: "Why did we need to make models of the tube in relation to making models of the moon, sun, and earth?" with no reference to real scientists. (Andrew)	Scaffolds may be superficial, inconsistent or incomplete (e.g., decontextualixed to moderately contextualized). *Exemplar*: In inquiry based activity with density asking: "How does this lab compare to how real science works? How is this lab like the tube activity?" and

Continued

Continued

		never linking the experience to real scientists. (Andrew, A6)
1	Nonexistent	Nonexistent
I. Students were required to reflect on explicitly identified NOS ideas in the lesson.		
5	Reflections required were explicit and in depth. *Exemplar*: In relation to models of the solar system: "Why do we still use this model even though it is flawed? Why do scientists use models even if they are not fully accurate? Why did we need to make models of the tube?" (Andrew)	Reflections required were consistently explicit and in depth. *Exemplar*: "It is often claimed scientific thinking is different than everyday thinking. To what extent do the force demonstrations and your experiences interpreting them support this claim? Be specific and give examples." (John, A2)
3	Reflections required may lack depth and or explicitness. *Exemplar*: Asking surface level questions such as: "Are models in science always the exact reality of what is out there?" (Matthew)	Reflections required may lack consistency, depth and or explicitness. *Exemplar*: Asking: "Why do scientists use scientific notation?" on a test (Mary, A2).
1	Nonexistent	Nonexistent

APPENDIX B: NOS-COP ILLUSTRATIVE VIGNETTES OF HIGH, MEDIUM, AND LOW NOS IMPLEMENTERS

High NOS implementation teachers incorporate decontextualized NOS activities (e.g., black box activities, puzzle-solving activities, NOS readings that are separated from science content) and ask questions that draw students' attention to and make them think about NOS ideas that those kinds of activities can illustrate (e.g., In what ways is this activity similar to what scientists do?, How does this black box activity illustrate that doing science requires creativity?, How does this activity illustrate that scientific problem solving doesn't follow a prescribed method or use supernatural explanations?, How does this activity illustrate that doing science often is a collaborative effort?). However, high implementers go well beyond these sorts of decontextualized NOS activities, consistently and seamlessly incorporating planned and spontaneous NOS instruction when teaching science content. For instance, high implementers often have their students involved in inquiry laboratory activities and engage students in NOS discussions and assignments by asking questions such as "How does your work in making sense of your laboratory data make clear that data does not tell you or scientists what to think?," "What role does data play in scientific thinking?," "How did your work in this laboratory activity illustrate that you did not follow a step-by-step scientific method?," "How is this similar to the work of scientists?," and "Describe three ways that the laboratory activity accurately portrayed the NOS." Even during interactive presentations targeting science ideas, high implementers raise NOS issues by asking similar questions (e.g., To what extent do you think classification schemes are invented/discovered?). At times, high implementers also incorporate authentic readings, work and words of scientists, and ask questions such as "How does the DNA work of James Watson, Francis Crick, Maurice Wilkins, Rosalind Franklin and Linus Pauling illustrate that doing science involves both collaboration and competition?," "How does the influence of Darwin's prior experiences on his thinking regarding how species evolve illustrate that scientists are not, and cannot be, totally objective?, and "How does the work of Alfred Wegener illustrate that data does not tell scientists what to think, but instead that creativity is part of making sense of data?" To assist students in making these NOS links, high implementers may refer their students to previously completed decontextualized and moderately contextualized NOS activities and ask questions that connect these situations (e.g., How is this scientist's work similar to your work with the black box activity?, How was your need to create an explanation to *account for* the laboratory data similar to what these scientists are doing?, How was your thinking during the thermometers activity similar to Deluc's?). High NOS implementers' summative assessments also include similar NOS questions, and students are expected to understand NOS just as they are expected to understand science content. High NOS implementation teachers' classroom practices make obvious that deeply understanding NOS is an important instructional outcome because such instruction occurs often, consistently, in a variety of contexts (from decontextualized through highly contextualized settings), and is assessed in a variety of contexts.

Medium NOS implementation teachers incorporate decontextualized NOS activities (e.g., black box activities, puzzle-solving activities, NOS readings that are separated from science content) and ask questions that draw students' attention to and make them think about NOS ideas that those kinds of activities can illustrate (i.e., similar NOS questions posed by high implementers). Furthermore, medium implementers require their students to further reflect about these ideas through similar questions present on summative assessments (e.g., quizzes, graded homework, and unit tests). However, despite proficiently incorporating decontextualized NOS activities and having their students reflect upon NOS ideas addressed in those activities, medium implementers have limited success going beyond these sorts of decontextualized NOS activities and incorporating planned and spontaneous NOS instruction when teaching science content. For instance, medium implementers often have their students involved in laboratory activities and science content discussions, and strive to engage students in NOS discussions while in those contexts, but they struggle and often fail *in the act of classroom teaching* to effectively draw students' attention to and make them think about relevant NOS issues in those contexts. In these instances, medium implementers typically resort to simply making NOS assertions (at times dubious or simplistic) or asking superficial NOS questions (e.g., telling students with no follow-up questions: "Science relies on empirical evidence and will not tolerate lying about results," "Researchers at this time worked together to discover that something smaller than bacteria could cause disease," or asking "How is this like science?"). In these instances, medium implementers often failed to engender accurate or meaningful discussion regarding relevant NOS issues present in the context of the science content being addressed. Unlike high implementation teachers, medium implementers infrequently incorporate authentic work and words of historical and contemporary scientists through assigned readings and homework. Even more infrequently did medium implementers utilize scientists' authentic work and words in the classroom to raise NOS issues. Medium implementers' difficulties with implementing NOS in the context of science content and authentic scientists' work prevents them from scaffolding NOS instruction across a continuum of varying contexts. While medium implementers may include in their summative assessments questions about decontextualized NOS activities (e.g., "In what ways did the black box activity require creativity?") and superficially refer to NOS during inquiry activities, they rarely situate NOS within the development of authentic science ideas and ask questions that connect these situations. Medium NOS implementation teachers' classroom practices provide ample evidence that understanding NOS is an important instructional outcome, but such instruction occurs sporadically and primarily (but not exclusively) in decontextualized contexts.

NOS summative assessments are also almost entirely situated in decontextualized NOS settings.

Low NOS implementation teachers, at best, incorporate NOS haphazardly, almost exclusively in decontextualized contexts, and in ways that at times portray mistaken simplistic and/or mistaken notions about NOS. Low implementers primarily incorporate decontextualized NOS activities (e.g., black box activities, NOS presentations divorced from science activities and content) and insipidly draw students' attention to NOS ideas, but those references at times convey mistaken NOS ideas. Moreover, low implementers' summative assessments contain superficial and, at times, problematic NOS questions regarding decontextualized activities (e.g., "How does the black box activity resemble science?," "Why are observations important in science?," and "What is the scientific method?"). Low implementers, even when they do incorporate decontextualized NOS activities, almost never refer to them when later teaching science content. In the rare instances where low implementers make efforts to raise NOS issues while teaching science content, their attempts appear as trivial "add-ons." Low implementers' common use of lecture and highly directive science activities afford few opportunities for accurately and effective addressing NOS. When low implementers do address NOS-related ideas during laboratory activities, teaching science content, or using authentic science examples (e.g., incorporating a worksheet about controlled experiments, addressing the development of the cell theory), such instruction is often rife with NOS misconceptions (e.g., claiming that scientists vote on science ideas, science is objective, data tell scientists what to think, or science follows a set method) and didactic. Low implementers miss clear opportunities for accurately and effectively teaching NOS, even when NOS teaching opportunities clearly arise during instruction (e.g., when students account for laboratory data in different ways). Low implementers' summative assessments are devoid of links between science content, authentic science examples, and NOS. Rather, low implementers' summative assessments focus primarily on assessing students' content knowledge and process skills. Low NOS implementation teachers' classroom practices provide little evidence that understanding NOS is an important instructional outcome. When low implementers do address NOS, such instruction appears almost exclusively in decontextualized contexts or as an add-on that is disconnected from the main thrust of a science lesson. Low NOS implementers convey simplistic and sometimes incorrect NOS ideas, and their summative assessments rarely address NOS.

APPENDIX C: CODING SCHEME FOR DETERMINING THE EXTENT THAT PARTICIPANTS' ARTIFACTS AND LESSONS REFLECTED AND/OR WENT BEYOND THEIR TEACHER EDUCATION PROGRAM'S PROMOTION OF NOS INSTRUCTION

Category	Exemplar
Incongruent	
NOS instruction is teacher generated and uses artifacts or pedagogical practices that originated from a source other than the teacher education program.	*Artifact*: Teacher generated lab with question that asks: "Why is it extremely important that scientists do not allow past experiences, or other people's ideas or what they want to be the

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Moreover, artifact or lesson explicitly portrayed NOS in a mistaken manner that is incongruent with what was promoted in the science teacher education program.	answer to influence their observations?" (Maddy: A53) *Lesson*: Teacher conveys that Mendel's data told him how genotypic ratios occur, observation precedes theory, and genius is required for scientific success. (Thomas: 11/11/2009)
Unclassifiable *Artifacts*: NOS is present in some discernable fashion, usually in materials that are not teacher generated (e.g., articles, text book tests). However, any NOS link is merely implicit and whether the teacher addressed the implicit NOS idea(s) is unclear.	*Artifact:* Popular media article that describes global warming with implicit NOS statements embedded (e.g., how politics and society influences global warming research). However, the implicit NOS idea(s) is not readily apparent to students, and no evidence exists that students' attention was drawn to the NOS idea(s). (Philip: A1)
Lessons: The NOS was not taught in a discernable fashion.	*Lesson*: Any lesson in which the NOS was not taught in any discernable manner. (Mary: 10/02/2009)
Replication Evidence indicates artifact or lesson was copied from the participants' preservice program. The teacher did not add to the activity or place the activity in a new context beyond what was demonstrated in their science teacher education program.	*Artifact*: Student assessment asking how a black box activity represents how science works. (Mary: A4) *Lesson*: Teacher uses a series of gestalt switches to demonstrate that perceptions are influenced by prior knowledge (i.e., not objective) (None observed)
Mixed Congruency Artifact or lesson possesses some attempt at effective NOS teaching resembling what was learned in the science teacher education program. However, major inconsistencies with how NOS was portrayed in the preservice program were evident in lessons and lesson artifacts OR pedagogical difficulties during lessons (e.g., difficulty asking questions to effectively draw students' attention to a NOS idea) thwarted attempt to fully and explicitly address NOS idea.	*Artifact*: Teacher-generated digital presentation addressed that no single scientific method exists and that science cannot include the supernatural, but later states that supernatural ideas, *unlike science*, cannot be *proven* or disproven, and claims science always begins with observation and follows a set process. (Maddy: A16) *Lesson*: Teacher began class by briefly addressing that science cannot account for the supernatural. The teacher then initiated an interactive presentation regarding the Earth's age, but made NOS statements of mixed accuracy (e.g., "Science will not tolerate lying in the scientific community" followed later by "if you are 99% correct with your data as a scientist you will be a millionaire scientist." (Peter: 10/08/2010)

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Extension	
Lesson or artifact illustrates that the teacher implemented NOS in a manner consistent with what was presented in their preservice program, but went beyond that and deliberately addressed NOS ideas and/or developed NOS activities in a novel or modified context.	*Artifact*: On a solar system project the teacher asked, "What are the reasons why Pluto is no longer considered a planet? Why did this idea change? How is this change in science like the black box activity or the gestalt switches? We cannot prove things in science. How is Pluto an example of this? (Andrew: A1) *Lesson:* Teacher uses black box activity not used in his preservice program to mimic Rutherford's Gold foil experiment and teach how scientists can account for unobservable phenomena. (Matthew: 10/06/2009)

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