Describing Teachers' Conceptual Ecologies for the Nature of Science

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ABSTRACT: This research focused on the interactionist conceptual ecologies of inservice teachers and how these ecologies influenced these teachers' conceptual frameworks for the nature of science (NOS). The participants in the study were five teachers enrolled in a graduate course focused on NOS. Data included participants' responses to open-ended and Likert scale surveys, interviews, writing prompts, and participant observations of classroom sessions. We propose a model of the interaction of the prominent components of teachers' conceptual ecologies for NOS, one in which learning dispositions, understandings of the broad enterprise of science, and orientation to learning and learners are understood to shape teachers' conceptual frameworks for NOS. The complex ties between NOS conceptions and goals, affect, dispositions, and beliefs speak to the inclusion of the bounded nature of science as a central aspect of NOS for practicing teachers. Teachers' dispositions toward learning this construct are linked to their conceptions of the boundaries of science as well as their understanding of the role of NOS in their own teaching. We argue that a recognition of the bounded nature of science foregrounds actions of a teacher's learning disposition, thus potentially minimizing the influence of their religious beliefs. © 2006 Wiley Periodicals, Inc. *Sci Ed* **90:**874–906, 2006

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INTRODUCTION

The original conceptual change theory as outlined by Posner, Strike, Hewson, and Gertzog (1982) is an epistemologically grounded model of conceptual change based on a learner's rational assessment of competing knowledge claims. Recently, Abd-El-Khalick and Akerson (2004) have employed the conceptual change model (CCM) to understand the nature of science (NOS) learning of preservice teachers. The selection of the CCM to understand NOS learning of teachers is appropriate, given that the CCM "concerns the alternation of conceptions that are in some way central and organizing in thought and learning" (Strike & Posner, 1992, p. 148), and clearly NOS can be considered to be central in learners' thinking about and with scientific knowledge (Duschl, 1990; NRC, 1996). Abd-El-Khalick and Akerson (2004) recognize the limits of the overly rational emphasis of the original CCM and attempt to expand this theory to better account for learning. They argue that "it is easy to claim that elements from a variety of domains significantly impact learning as conceptual change, it remains crucial to elucidate the elements that gain special importance when learning about specific subject matter" (Abd-El-Khalick & Akerson, 2004, p. 786).

One of the objectives of this research is to answer this call, which is to describe the personal elements that gain importance when one is learning about the nature of science. Our work promises to inform discussions surrounding both conceptual change and the nature of science. Working from a broad range of literature in science education (conceptual change and nature of science) and educational psychology (intentionality, learning dispositions, motivation and affect in learning), and situating this analysis in the real world of classroom learning (Sinatra, 2005), our research focuses on the interactionist conceptual ecologies of inservice teachers and how these ecologies influence these teachers' conceptual frameworks for the NOS. In conceptual change theory, an interactionist conceptual ecology is thought to be the changing conceptual environment in which conceptual change occurs—*interactionist* as this environment influences the change of the conception and this change also influences the environment. This conceptual environment is thought to include cognitive aspects and affective, dispositional, and social and cultural influences. Because the interactionist conceptual ecology has been a prominent aspect of the CCM for well over a decade, we argue that it is well suited to account for the extrarational aspects of NOS learning, and through this work we strive to describe the aspects of the conceptual ecology that have particular importance in shaping the NOS learning of inservice teachers.

Conceptual Ecologies

As it was originally proposed, the CCM (Posner et al., 1982) was intended to describe only the change of major, organizing conceptions. The CCM models the process of conceptual change for individual learners after patterns of paradigmatic changes in science as described by Kuhn (1970) and informed by Toulmin (1972) and Lakatos (1970). Using the original CCM, learners are understood to logically evaluate the utility of conceptions to account for data or evidence. If a learner is unsuccessful in using a conception to account for anomalous data, then a second, competing conception is sought. As described through the CCM, learners then compare competing conceptions. Through the process of rational comparison, learners are thought to experience change only if the new conception is found to be more intelligible, plausible, and fruitful than the competing, pre-existing conception.

A decade after the original conceptualization of the CCM (Posner et al., 1982), two of the authors of this groundbreaking model, Strike and Posner (1992), suggested that the original model's reliance on rational belief may "generate some blind spots" (p. 152), a critique that resonated and has been continued through the efforts of a host of other researchers as they worked to push past the rational, logical, strictly cognitive confines of this model (c.v. Alsop & Watts, 1997; Demastes-Southerland, Good, & Peebles, 1995; Pintrich, Marx, & Boyle, 1993; Venville & Treagust, 1998). Indeed, these authors, and many others in the research communities of both science education (Alsop, 2005; Lee & Anderson, 1993) and educational psychology (Pintrich, 1999; Sinatra, 2005; Sinatra & Pintrich, 2002) explain that goals, emotions, dispositions, and motivations interact with cognitive constructs to play a significant role in shaping learning. Based on this work, which Sinatra (2005, p. 107) refers to as a "warming trend" for conceptual change research, it has long been acknowledged that our understandings of conceptual change must take into account the significant influence of a learner's motivational and affective orientations in science learning. Such accountings are featured prominently in recent models of conceptual change in educational psychology (Dole & Sinatra, 1998; Gregoire, 2003).

The science education community's response to the need to account theoretically for the role of affect, belief, and other extrarational factors in conceptual change has centered around expanding our understanding of the influence of the conceptual ecology on the change process. The original formulation of conceptual change (Posner et al., 1982) includes Toulmin's (1972) notion of a conceptual ecology. Analogous to Cobern's (1993) *world view*, this conceptual ecology includes learners' epistemological commitments, anomalies, metaphors, analogies, metaphysical beliefs, knowledge of competing conceptions, and knowledge from outside the field, all of which impact the restructuring of conceptions. Strike and Posner's (1992) revisions of the CCM describes an "interactionist" conceptual ecology, one in which conceptions are understood to (a) shape this conceptual ecology and (b) be acted upon by other components of the ecology. In addition to revising the action of the conceptual ecology, many have argued to expand what is thought to be included in this ecology, including not only prior conceptions but also beliefs, goals, emotions, and motivation (Demastes-Southerland et al., 1995). Although more recent work proposes an additional construct, the learning ecology, be added to the CCM to account for the extrarational aspects of learning (Abd-El-Khalick & Akerson, 2004), we argue elsewhere that Strike and Posner's expanded notion of a more inclusive, interactionist conceptual ecology already allows the CCM to explain the extrarational aspects of science learning (Southerland, Sowell, & Johnston, in preparation). Thus, we reject the utility of the proposed learning ecology and instead focus on the conceptual ecology as a means to understand the role motivation, dispositions, and beliefs have on shaping science learning.

Working from this generalized description, as we approached this research we sought to "flesh out" the conceptual ecology for NOS. Our own work in controversial topics reveals that a learner's personal characteristics (such as need to validate other sources of personal interest, personal comfort challenging authority) can play important roles in a learner's conceptual ecology (Demastes-Southerland et al., 1995). Given that current portrayals of NOS are so counter to most teachers' traditional "knowledge about science" (Duschl, 1990), in this research we drew on past generalized descriptions of conceptual ecologies, paying particular attention to components that seem to be influential in shaping the learning of controversial topics. To augment this we looked to Tsai's (2002) work that describes that teachers' understandings of the nature of science are "nested with" or closely related to their view of learning and teaching, as well as their attitudes toward the capabilities of students to learn science. We also drew on the findings of Abd-El-Khalick and Akerson (2004) and Sinatra, Southerland, McConaughy, and Demastes (2003) in terms of their discussion of the role religious beliefs may play in the learning of nature of science.

To inform our descriptions of conceptual ecologies for NOS, we also looked to the work of educational psychology. Sinatra and Pintrich (2002) describe that conceptual change can often be goal-directed and conscious and is influenced not only by cognitive processes but also by metacognitive and motivational processes. For instance, Stanovich's (1999) work describes how learning is influenced by the learner's goals. Pintrich (2000) has shown that achievement goals, particularly mastery goals, highly influence the nature of learning, as students with a mastery goal in an area are more likely to engage with material, seeking new information to further their understanding.

Similar work also points to the role of "dispositions" in shaping learning (Stanovich, 1999). "One can think of dispositions as tendencies toward learning and thinking" (Southerland & Sinatra, 2005). Researchers have described that learners' tendency to think in an open-minded fashion and to weigh new evidence against a personal belief account for significant differences in reasoning performance (Sa, West, & Stanovich, 1999; Stanovich, 1999; Stanovich & West, 1997, 1998).

Informed by this wide range of work within both science education and educational psychology, we understand that attempts to describe teachers understanding of nature of science must be broad and multifaceted, so that they take into account epistemological beliefs, motivations, goals, learning dispositions, knowledge within and without the content of nature of science, religious beliefs, as well as views of learning and learners.

Nature of Science

In this research we focus on teachers' conceptual ecologies regarding NOS. The NOS includes the characteristics of scientific knowledge, the epistemology of science, its presuppositions, methodological assumptions, goals, and boundaries, as well as the conventions underlying the knowledge produced through science (Lederman, 1998). It is, most essentially, a set of underlying principles describing what makes science "science." It is argued that to truly understand science in a nontrivial manner, one cannot simply understand a few choice scientific concepts (e.g., photosynthesis, conservation of matter, the age of the Earth), but must also recognize the unique characteristics of the knowledge that science produces. It has been argued that for one to make informed personal and societal judgments as a citizen (i.e., to experience the benefits of science literacy), one must understand how science works and how those processes shape the nature of scientific knowledge (AAAS, 1990, 1993; NRC, 1996). Education that focuses in part on the nature of scientific knowledge, then, goes beyond simply educating students about scientific principles; rather, it is an active attempt to empower citizens to shape and maintain a democratic society.

Given the prominent role that the nature of science is understood to play within reform-based science education, there has been a flurry of philosophical discussions about the most appropriate characterization of the nature of science. We must recognize that there remain numerous controversies regarding the "appropriate" characterization of the nature of science in the philosophical and science education literature (e.g., that represented in the discussions of Matthews, 1994; Siegel, 1997; Stanley & Brickhouse, 1994 or Good, 2005; Poole, 1996; Smith & Scharmann, 1999). That said, it is important to recognize that there is some consensus in the science education community on a number of important NOS aspects deemed critical for students to understand: that scientific knowledge is empirical, tentative, creative, subjective, and socially and culturally constructed (AAAS, 1993; Lederman, 1992; McComas, Clough, & Almazroa, 1998; McComas & Olson, 1998; NRC, 1996). Despite the heated discussions as to the finer points of most appropriate portrayal of the nature of science and a strong critique of the manner in which NOS is sometimes approached (Elby &

Hammer, 2001; Rudolph, 2000), the consensus view of NOS is a visceral component of current science education reform efforts. Given its prominence, the consensus view of NOS has played an important role in shaping the preparation of science teachers in recent years and so it serves as the framework both for the instructional approach used in this research and our analytical lens.

Research Focus

If we are to realize the promise of reforms, clearly constructing a better understanding of teachers' conceptions of the nature of science is fundamentally important. Although it is clear from the voluminous research that NOS pedagogy needs to be explicit, reflective and activity based (e.g., Akerson, Abd-El-Khalick, & Lederman, 2000), perhaps we can now turn our attention toward intricate facets of such instruction. For instance, Sinatra and Pintrich (2003) describe that a curriculum needs to be informed by knowledge of learners' motivation and affect toward specific content, thus we anticipate that investigations into teachers' conceptual ecologies for NOS will be useful for informing future NOS curricula.

For our research, we pursued a line of inquiry in order to empirically describe prominent features of the conceptual ecology for the nature of science of practicing teachers. We were particularly mindful of the various facets of the CCM (dissatisfaction, intelligibility, plausibility, and fruitfulness) and their relevance to teachers' understandings and applications of the NOS (Hewson & Thorley, 1989). Thus, we sought to move beyond the more straightforward issues of intelligibly and plausibility of NOS constructs and also to take into account the fruitfulness of the concept for the teachers' thinking about a different domain: their classrooms.

METHODOLOGY

The participants in this research were five teachers enrolled in a graduate course that focused on the nature of science and science teaching. To generate the conceptual framework and conceptual ecology descriptions, we employed a variety of data: classroom interactions, course writings, teachers' responses to surveys, and exit interviews. Although the findings of all five teachers were used to address the research focus, the case studies of three of these teachers are reported in detail.

Instructional Context

The participants focused on in this research were students in a graduate-level course in education entitled *The Nature of Science and Science Education*, offered at a university in the United States' intermountain west. This course involved students who were teachers with placements ranging from the primary level through the upper grades of high school science. Teachers took this course for a variety of reasons, including MS degree requirements as well as collecting teaching ideas.

During the semester of the research, a very diverse set of attitudes and backgrounds regarding science and education were found in these students. The backgrounds ranged in terms of students' science backgrounds, their teaching experiences, and their teaching interests. The course was designed to simultaneously address all backgrounds as adequately as possible. From the course syllabus:

> What is "science" and what facets of science are important to teach in the classroom? Recently (and historically), reformers in science education have been advocating that students

> (and their teachers) need to understand the "nature of science" (NOS), the basic philosophical assumptions of science. But what are these fundamental assumptions of science? How do they play out in the practice of science and in the society in which science operates? And, how does science get portrayed in the classroom? This course looks to develop ideas of what the NOS is and how it is incorporated into the classroom. We will investigate what the basic ideas of the NOS are, how well these ideas are understood by learners, how these ideas are typically displayed in our classrooms and society, and how science education can be best shaped in order to model and explicitly teach the NOS appropriately.

The course was offered during a 6-week block, with two class sessions per week. The course was structured around the central tenets of NOS as well as NOS pedagogy. All instruction included the explicit, reflective, activity-based approach described by Abd-El-Khalick and Akerson (2004) and Khishefe and Abd-El-Khalick (2002), meaning that for each class session select aspects of the nature of science were targeted, activities and readings were designed to address these concepts, and through discussions and readings students were supported in their reflection on their own understandings in comparison to the portrayal of NOS that emerged from the discussions (e.g., Loving & Foster, 2000). Outside of class, students were expected to prepare weekly response papers and prepare for discussions of course readings that occurred each class session. The course culminated in a final paper and exit interview in which students were to synthesize what they had learned, both in terms of the content of the nature of science as well as its role in their classroom. (See Appendix A for an outline of the course.)

Participant Selection

The nine students in the course were all teachers, each at different places in their careers, and each teaching in different settings. They ranged from a first-year teacher in a first-grade classroom, to a high school and middle school biology teacher finishing a master's degree and teaching licensure while employed, to a veteran physical science teacher who had been away from the classroom for several years. Collectively, these teachers taught in grades ranging from kindergarten to high school; and, their science backgrounds ranged from those with graduate training in the sciences to those who had taken only the minimal amount of science in order to receive an elementary education degree.

Although data were collected for each of the teachers in the course, we selected five contrasting case studies for this study, three of which will be presented in some detail. The purposeful sampling (LeCompte & Preissle, 1993) included five teachers that represented a wide array of orientations to science, views of learning, teaching philosophies, and engagement levels in the course.

To inform our purposeful sampling, we also looked at the results from a web-based NOS instrument which each of the participants took twice, once at the beginning of the semester and again upon completion of the course. This instrument, part of *Scientific Thinking and Internet Learning Technologies* (STILT) (Southerland, Settlag, Johnston, Scuderi, & Meadows, 2003b), allowed us to select individuals who demonstrated varying degrees of change regarding their NOS understandings, at least in terms of their scores on the instrument. Although we did not rely on their responses to this instrument during later phases of data analysis, they did provide information useful in selecting individuals who were engaged with the material at different levels of sophistication.

Data Collection

Data were collected from multiple sources, using multiple methods. Primarily, data were drawn from students' assigned work in the class, including response papers and other writing prompts. (See Appendix B for writing prompts and data collection tools.) Because the learning objectives for the course were to elicit and develop teachers' understanding of the NOS, teachers' work in the course reflected both their NOS understandings and related affect. Additionally, because this course was designed for practicing teachers, much of this work required them to draw upon the context of their own classrooms. This combination of data enabled us understand how these teachers conceptualized the nature of science and how they envisioned teaching it.

Several measures of student understanding used within this course were previously developed for research purposes. These "standard" types of measures included specially selected questions from the views of nature of science (VNOS) questionnaire (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002), the STILT forced-choice measure on nature of science and scientific inquiry (Southerland et al., 2003b), and responses to an epistemological survey (Schommer, 1990).

At the conclusion of the course, the instructor received final papers from each student (described in Appendix B) that called for their most explicit and developed descriptions of their conceptions of NOS, its place in their classrooms, and what they considered to be the most effective method of NOS instruction. In order to clarify our interpretations of their responses, the instructor conducted an exit interview with each student after the final papers had been graded. These interviews, conducted after the completion of the course, were useful in providing a full debriefing of the students' learning. These interviews were audiotaped and transcribed. In addition to written work and interviews, the course instructor compiled field notes during the course describing each student and their class interactions.

Data Analysis

Data analysis initially occurred in a bifurcated fashion of analysis. One member of the research team first reviewed all the data for an individual teacher searching for evidence to describe different aspects of that participant's conceptual ecology for NOS, while a second researcher began a similar process, analyzing all available data to describe different aspects of that participant's conceptual framework for NOS.

Possible Components of NOS Conceptual Ecologies. The quest to identify the major components of the teachers' conceptual ecologies for NOS caused us to "cast a broad net," and our data analysis was guided by a wide variety of prior research, including that of outlining possible components of conceptual ecologies in general, for nature of science in particular, other potentially controversial science topics, as well as the related work from educational psychology. Thus, our analytical approach to all the data was structured the following categories (see Table 1 for data exemplars):

a. *Past science experiences*, both in school and out of school.
b. *Affect toward science*, both school science and more traditional science. Here, we sought data to describe how the participants felt about science, both in terms of "doing" school science and professional/research science.
c. *Self-efficacy*, both for the learning of science as well as their sense of efficacy in terms of teaching science (such as that described by Riggs & Enochs, 1990).

TABLE 1
Data Exemplars for Components of Participants' Conceptual Ecologies

Specific Construct	Exemplary Quotes or Other Evidence for the Negative Aspect of This Construct	Exemplary Quotes or Other Evidence for the Positive Aspect of This Construct
Past science experiences	[Their own personal descriptions or lack of descriptions.]	[Their own personal descriptions or lack of descriptions].
Affect toward science	"I can do it, its just I've never really focused on it, its just not. . . me" —Donna	"I still enjoyed science though. I think of many wonderful [trips]. . . visiting many national parks was my first catalyst for my interest in geology" —Sarah
Self-efficacy (for science, for teaching)	"I struggled at first as the subject matter (science) is the one I had trouble grappling with" —Sarah	"I have always been confident in any class I was enrolled in" —John "I already teach all of this" —Donna "I feel confident that my students won't be harmed by my methods" —Donna
Learning disposition—open-minded thinking	"I'm an unbearable know-it-all" —Donna [Personal interactions in class discussion that halted reasoning divergent to their own.]	"If I don't agree with your point, then that's okay" —Sarah "I hate close-mindedness" —Megan
Learning disposition—need for cognition	"I refuse to expand on something. . . that can't be agreed upon" —Donna [Supporting this assertion, she excerpted large sections from an earlier paper in her final paper of the course.]	Sarah's comments that she wants more reading in the class. "I've had this class, I want more" —Sarah "I'm just curious" —Sarah "I've loved all the work in this class, because I feel that I've really learned from it" —Megan
Learning disposition—comfort with ambiguity	"I need an answer, I wanted to know what. . . . and there's no answer" —Sarah "I refuse to expand on something. . . that can't be agreed upon" —Donna	"The nebulousness of science intrigues me" —Sarah
Learning disposition—reflective thinking	[Lack of any impromptu reflective analysis of ideas during class or interviews was taken as lack of reflective thinking.]	"I'm a simple thinker" —Sarah "I came to this class thinking that there was a certain methodology of science that gave us an absolute truth" —Lisa
Epistemological belief—recognition of multiple authorities	"There are so many views. . . why can't you [science educators] agree?" —Donna	"I'm not looking for the 'right answer' but a way to figure it out"; "I think it is good for them [my students] to know that I don't know everything"—Megan

Continued

TABLE 1
Data Exemplars for Components of Participants' Conceptual Ecologies (*Continued*)

Specific Construct	Exemplary Quotes or Other Evidence for the Negative Aspect of This Construct	Exemplary Quotes or Other Evidence for the Positive Aspect of This Construct
Beliefs about learners and learning	"This tentative nature of science is too confusing for my students" —Donna "I really have to dumb it down for [my students], and it's because of the hormones and they're into the boy–girl. . . " —Lisa	"My students are eager to learn. . . I believe they are capable of learning so much" —John "I believe they [first graders] can understand that science can be tentative" —Megan
Conception of science as an enterprise	[If their all of their comments focused on the questioning process of science. Alternatively, if they only described the knowledge produced in science.]	[If their comments included a mixture of descriptions of the processes of science as well as the knowledge produced through science.]
Religious beliefs	[No negative evidence of students' religious beliefs found in this study.]	"Everything is God. . . science is a subset of religion" —Donna "I see science as separate from religion, but not contradictory to it" —Sarah

d. *Learning dispositions and related general epistemological beliefs.* Because the nature of science as presented in the course was so counter to the conception of science that many of the teachers held beforehand, a degree of willingness to examine one's beliefs and entertain alternative points of view, the disposition to not reject ideas that are at times ambiguous and for which there are many different positions advocated by a host of experts, was perceived to be a likely factor in developing a robust understanding of the nature of science. Some of the dispositions and general epistemological beliefs described in the literature that we felt might be productive included:

i. *Actively open-minded thinking* (Stanovich & West, 1997), a construct that assesses the tendency to be open to ideas that may conflict with one's own.
ii. *Need for cognition*, described by Cacioppo, Petty, Feinstein, and Jarvis (1996), assesses the tendency to engage in effortful thinking;
iii. *Absolutism*, described by Erwin (1983) as the disposition to seek a single right answer or their intolerance of ambiguity;
iv. their belief that knowledge comes from a single authority (Schommer, 1990); and
v. the disposition to participate in reflection about one's knowledge and thoughts in relation to what is learned also seemed to be likely candidates for a conceptual ecology for NOS.

e. *Beliefs about learning and learners*. Given Tsai's (2002) work, we also sought information about each participant's view of learning and teaching, as well as their attitudes toward the capabilities of students to learn science and, specifically, NOS. It may be useful to think of their beliefs about learning and learners as what the literature more aligned with educational psychology would describe as the *outcome expectancy* (Riggs & Enochs, 1990) for teaching students NOS.

f. *Conceptions of science as an enterprise*. For this we explored the teachers' overall views of science and scientific inquiry, explicitly focusing on if they understood science largely in terms of the products of science (the knowledge it produces), the processes of scientific inquiry, or some combination of both these perspectives (Gess-Newsome, 2002).
g. *Religious beliefs*. As suggested by past work in NOS learning (Abd-El-Khalick & Akerson, 2004; Johnston & Southerland, 2001), our data analysis highlighted evidence of teachers' belief systems and how these interacted with other features of their conceptual ecologies to influence their NOS conceptual frameworks. (The reader should note that this construct was not found to be central in shaping NOS understandings, as is discussed.)

Collectively, this set of descriptors provided a matrix used to guide our analysis of the data.

Teachers' Conceptual Frameworks for NOS. A specific description of participants' NOS frameworks was constructed by engaging with the existing science education literature to flesh out the individual components that make up an understanding of the nature of science. Current literature within science education regarding the NOS (e.g., Khishefe & Abd-El-Khalick, 2002; Lederman et al., 2002; McComas, 2000) was reviewed in order to identify the most central concepts. These included

a. the empirical nature of scientific work;
b. the distinction between evidence and explanation;
c. the differences between theories and laws;
d. the role of creativity;
e. the theory-laden nature of science;
f. the sociocultural embeddedness of scientific knowledge and process;
g. the methods of science;
h. the tentative nature of scientific knowledge; and
i. the bounded nature of science.

Table 2 shows data exemplars for components of participants' conceptual frameworks for nature of science.

Although much of this list is very well known to the NOS research community, the last concept was a new addition. Past research compelled us to investigate the degree to which the teachers understood science as its own way of knowing (Smith & Scharmann, 1999; Southerland, 2000). This aspect of the NOS conceptual framework is often either ignored or only implicitly included in conversations regarding the influences of religion on NOS understandings. However, as our interpretations of the findings emerged, we took notice of how the participants' writings not only worked to compare/contrast religion to science but also provided us with unique portraits of how they drew boundaries around science, defining it as a unique and distinct way of knowing (Poole, 1996). Although we compiled a list of NOS concepts, we recognize that these are very much interconnected and interdependent, with a student's understanding of one component supporting, and at times contradicting, her understanding of another component.

TABLE 2
Data Exemplars for Description of Participants NOS Frameworks

NOS Concept	Exemplary Quotes (Moderate Level of Sophistication)	Exemplary Quotes (High Level of Sophistication)
Empirical NOS	"Scientists collect and interpret empirical evidence." —Lisa	"Observations are constrained by our perceptual apparatus and are inherently theory-laden." —Sarah
Evidence vs. explanation	"An observation is something we witness, or see, and then we try to infer something based on what we have observed." —Meagan	"Science is based on evidence. . . Whatever the means are by which a practitioner of science gathers her data, that data must be interpreted to create an explanation." —John
Theory vs. law	"Scientific laws are certain rules we use to generalize different phenomena in nature that we get from observing and experimenting with facts. They are used to predict things like the Laws of Motion. Scientific theories are what we use to explain the scientific laws." —Meagan	"[A law] is a descriptive generalization meaning an explanation of how something behaves in a given situation, while a theory is an attempt to explain exactly what causes the behavior." "A theory is not any more tentative than a law." —John
Theory-laden NOS	"In order to build a tall skyscraper, one must begin on the ground. A theory, whether basic or complex, is the ground floor of scientific knowledge. Scientists must have something to build and expand on. I the absence of theories there would be no progress." —Donna	"Even though scientists in both groups have access to and use the same set of data to derive their conclusions, [different conclusions] would possibly be because of their background knowledge and or different understands of ideas and theories applied to the same set of data." —Lisa
Creative and imaginative NOS	"The experience of creative insight. . . [fosters] a sense of the limitations of the scientific method, and therefore an appreciation of other ways of knowing. . . The scientific method as I see it, cannot alone give us total understanding." —Lisa	"Because all conclusions in science are creations of the observer, creativity is an important component of the NOS." —John

Continued

TABLE 2
Data Exemplars for Description of Participants NOS Frameworks (*Continued*)

NOS Concept	Exemplary Quotes (Moderate Level of Sophistication)	Exemplary Quotes (High Level of Sophistication)
Tentativeness of scientific knowledge	"Change can occur, not just from our dynamic world and processes that act on and within it but also from new ideas and theories coming to the scientific front and replacing or enhancing pervious discoveries and knowledge. This supports the ideas that science is a human endeavor from past history on through the present." —Sarah	"Any body of knowledge that is not highly skeptical of its own conclusions and assumptions is not scientific.... Ideas in science are not considered tentative because of their weakness. They are tentative because scientists must leave open the possibility of new or better explanation.... Scientific inquiry is not an absolute way of knowing 'truth'." —John
Sociocultural embeddedness	"[Science] reflects the social and cultural values of the culture in which it is practiced." —Donna	"Everyone has different backgrounds that influence the way they perceive observable events." "[Science] is composed of the underlying principles and culture that make science what it is... characteristics or values, it is also made up of certain attitudes and habits of mind." —John
Bounded NOS	"There are things that are better explained by science, however there are things that science cannot explain, and this is where other ways of knowing come in, for instance religion." —Meagan	"Science and religion are different in the way they interpret the world, and with what each considers to be a reliable means to validate these interpretations." —John

In contrast to other work into teachers' conceptual frameworks for NOS, in this research we sought to pay particular attention to the status a concept held for the teacher. Thus, the data for each of these concepts were reviewed to determine the intelligibility, plausibility, and fruitfulness of the concept for the teacher. Drawing on the work of Hennessey (1991, 1993), Hewson and Thorley (1989) before her, and a host of authors that followed (e.g., Blanks, 2000), we understood *intelligibility* to be a measure of how well an idea "made sense" to the teacher. In this study, we determined this by ascertaining how well the teacher could explain the NOS concept, and how readily the teacher could give examples of the concept. Likewise, we understood the *plausibility* of a concept for the teacher to be determined by the fit of the concept with the teacher's other knowledge or beliefs. Did the teacher find the concept likely or believable? Finally, *fruitfulness* was understood to be determined by how well the concept helped the teacher solve new problems, either within her own understandings of NOS or within their science teaching. Did this new NOS concept provide the teacher new ideas or ways to approach her teaching? Did the teacher find advantages of the NOS concepts for her teaching?

It is important to note here that while a concept's status was of particular importance to the research team, explicit discussions and negotiations of status as have been conducted in Gertrude Hennessey's classrooms (Beeth & Hewson, 1999) were not a feature of this course. Instead, we looked to the original conceptual change theory as a rationale for investigating a concept's status for the learner, recognizing that to understand a learner's conceptual framework, one must understand the relative epistemological "weights" for the concepts in that framework. Although descriptions of the fruitfulness of a concept for one's teaching would be informed through analysis of classroom teaching, our research ends at analyses of teachers' consideration of NOS for their classrooms. We recognize that teachers' classroom teaching is shaped by a wide range of forces (e.g., appropriate pedagogical content knowledge, materials, time, cultural expectations), with their content knowledge (including NOS knowledge) being only one of these forces (Southerland, Gess-Newsome, & Johnston, 2003a). Because this research focused on teachers' NOS conceptual frameworks and the ecology in which these frameworks reside, we argue that classroom observations would provide a complexity and scope of data too broad for this study.

Identifying the Interactions of Components of the Conceptual Ecology. Following the first level of analysis, for each teacher we had two descriptions, one of their conceptual ecology for NOS and one of their conceptual framework of NOS. Looking across these two descriptions within each teacher, aspects of the conceptual ecologies that were useful in explaining the conceptual framework were noted and described. After this within-case (teacher) analysis, we then sought trends common across individuals in the interactions of teachers' NOS conceptual ecologies and conceptual frameworks.

Rigor of Analysis. All data analysis proceeded through a series of "tests" against data, conducted in the following manner. One member of the research team, upon developing a description of the teacher's conceptual ecology or a description of the teacher's NOS understanding, would then go back to the data to determine if such a description was appropriate, taking particular care to search for negative cases. In situations in which the description was not supported by the data set, the description was revised and the process was repeated. Following this, a second member of the research team judged these descriptions, again looking specifically for negative instances of such a description evidenced in the data. Finally, all descriptions were brought to the course instructor (the second author), who compared these descriptions to his field notes and data from the exit interviews.

RESULTS AND DISCUSSION

In the following sections, we examine teachers' conceptual frameworks for NOS as well as the environment in which these frameworks are housed, that is, their conceptual ecologies for NOS. This examination was conducted in order to be able to identify the most important, influential components of those ecologies. For these investigations, we employed the data from the five participants, although only three will be described in detail. Although all five of these participants entered the course with various degrees of sophistication of their NOS frameworks, upon course completion, each of their frameworks could be traditionally categorized as overall *sophisticated*. (We offer this with some hesitation, recognizing that an NOS framework is composed of a number of different conceptions and that there could be a significant degree of variation in sophistication for the various components of NOS conceptual framework.) This overall degree of sophistication at the end of the course was surprising to us as researchers, knowing the difficulty that learners typically experience in coming to understand the NOS. However, throughout the results we will point out the aspects of each individual's understandings that were noticeably more or less sophisticated. Since the demands of the course required students to demonstrate their NOS knowledge, we found it useful to note which areas of the NOS canon the students emphasized, drew applications from, or addressed on a very superficial level.

We engaged in data analysis mindful of conceptual change theory and so it was clear that our participants' understandings could be characterized as overall sophisticated on the level of intelligibility and perhaps even plausibility. However, what became obvious in our analysis was that there existed significant differences in terms of the participants' recognition of the fruitfulness of these ideas. In other words, each of these teachers came to understand the central tenets of NOS (finding them intelligible) and many came to recognize that these notions were viable descriptions of the characteristics of scientific knowledge (finding them plausible). However, one important way the teachers differed was in terms of their recognition of the fruitfulness of these conceptions outside of the boundaries of the context in which they were learned. Because these participants were classroom teachers, an important measure of their conceptualization of fruitfulness of NOS employed in this study was the degree to which these teachers understood the aspect of NOS to solve new problems in their science teaching. Indeed, we argue that researchers need to be mindful of the status of conceptions in NOS research. For this, we must go past simple description of intelligibility in NOS; we must begin to widen our analytical frame to also account for plausibility and fruitfulness of NOS ideas.

Our results consist of an examination of the conceptual ecologies and conceptual frameworks for NOS for each of five teachers, followed by a discussion of the interaction of these ecologies and frameworks. Being a component of an "interactionist" ecology, we recognize this NOS conceptual framework to be shaped by, and in turn shape, the various factors that also reside in this ecology. In turn, we posit that the terrain of the conceptual ecology would look different as one considers other concepts to be learned, other conceptual frameworks. Three case studies will be presented in detail with information from all five participants being presented in a more condensed fashion.

Donna: The Pragmatic Reductionist of Classroom Science

NOS Conceptual Ecology. Donna had just finished a degree elementary education in the year before this class, and had just begun teaching in an elementary school. During the course, she accepted a position teaching 7th grade math in a school and district emphasizing integration between disciplines. This change was particularly interesting because during the latter portions of this class she very much positioned herself as a math teacher, not an elementary (or generalist) teacher. (See Table 3 for a summary of Donna's conceptual ecology for NOS.)

Donna's constellation of learning dispositions influenced her to superficially consider the nature of science and to reject its fruitfulness for informing classroom science. These dispositions included the following:

- A moderate self-efficacy for science coupled with a high efficacy for teaching.
- A distaste for ambiguity within NOS discussions, coupled with her strong need for an external authority, and low degree of open-mindedness to new ideas.
- Unlike some of the other learners in this study, Donna was not highly reflective in terms of her NOS learning. We found few instances in which she looked back on

TABLE 3
Overview of Participants' NOS Conceptual Ecologies

	Donna	Sarah	Meagan	Lisa	John
Past science experiences	Limited formal and informal	Extensive formal; limited informal	Limited formal; extensive informal	Limited formal and informal	Extensive formal and informal
Affect toward science	Poor—limited interest	Favorable—despite poor personal experiences	Favorable—high interest	Moderate—limited interest	Favorable—high interest
Self-efficacy (for science, for teaching)	Teaching—high; Science—high	Teaching—high; Science—low	Teaching—high; Science—high	Teaching—high; Science—low	Teaching—high; Science—high
Learning disposition—open-minded thinking	Weak—self described "know it all"	Strong	Strong	Moderate	Strong
Learning disposition—need for cognition	Weak	Strong—in terms of classroom applications	Strong	Weak	Strong
Learning disposition—comfort with ambiguity	Weak	Strong	Strong	Strong	Strong
Learning disposition—reflective thinking	Weak—limited reflection in this arena	Strong	Strong	Weak—limited reflection in this arena	Strong

Continued

TABLE 3
Overview of Participants' NOS Conceptual Ecologies (*Continued*)

	Donna	Sarah	Meagan	Lisa	John
Epistemological belief—recognition of multiple authorities	Naïve—sought single authorities	Moderately Naïve—limited need for a single authority	Sophisticated—recognized multiple authorities	Moderately Naïve—limited need for a single authority	Sophisticated—recognized multiple authorities
Beliefs about learners and learning	Reception view of learning: Low expectation of learners	Learning viewed as complex and difficult; High expectations of learners	Constructive view of learning; High expectations of learners	Learning involves problem solving; High expectations of learners	Constructive view of learning; High expectations of learners
Conception of science as an enterprise	Product	Process—primarily a "way of thinking"	Process	Process	Process and Product
Religious beliefs	Strong	Strong	Strong	Strong	Strong
Goal in course	Performance goal—grade achievement	Almost sole focus on immediate classroom applications	Mastery—understanding and translation to classroom	Almost sole focus on immediate classroom applications	Mastery—understanding translation to classroom, entry to academia

> her learning or on her ideas without an explicit prompt from the course instructor. Although Donna was frustrated with the ambiguous nature of the NOS discussions ("There are so many views of this."), she made it clear that her own understandings were solidly in place ("I'm already doing all this in my classroom"). Thus, she displayed very limited need for cognition in this area.

Donna's comfort with science did not come from a strong sense of success in learning science, but rather from her ability to "break down" science courses into manageable bits, and then "doing" those bits. Donna had a very reductionist, classroom-based understanding of science, seeing science as bits and pieces to be dealt with in order to earn a grade. Indeed, she used this reductionist approach to science in her classroom teaching, explaining that the role of the teacher was to help students "break [science] down" so they could memorize it. Given these dispositions and beliefs, it is not surprising that Donna understood science almost completely in terms of its products. Nested alongside this product view of science was her reception model of learning in general, along with her assertion that students were not especially capable of receiving science knowledge. Given her product orientation to understanding what science is, her own reductionist approach to learning and teaching, and her low estimation of the capabilities of learners, it was not surprising that she foresaw little utility for NOS in the classroom.

Donna's class writings were interesting for us to analyze. Two distinct phases of thought were discernable: an initial strong resistance to NOS as an overall topic, followed by her efforts toward constructing a high degree of intelligibility for individual concepts of NOS. Her initial resistance was based on the mistaken notion that the goal of the course was to provide teaching "activities." It required half of the course's term for Donna to understand that the central goals of the course were for students to understand the nature of science and scientific inquiry. Therefore, when she realized that her "job" in the course was to become familiar with the epistemology of science, she did it. She mastered NOS in terms of intelligibility of its individual components, but made no efforts to move past intelligibility or to integrate these components.

NOS Conceptual Framework. Donna's weakest areas of sophistication of her NOS framework revolved around the unique functions of theories and laws, as well as conceptions of the creativity and tentativeness of scientific knowledge. (See Table 4 for a general description of Donna's conceptual framework for NOS.) Although she valued the role of extrarational influences on scientific work, her discussions about whether or not scientific knowledge is created or discovered reflected a belief that science often works to "uncover the workings of God." This "uncovering" belief about science clearly contradicts a robust understanding of the creative aspects of scientific knowledge. This belief can also be seen as influencing her understanding of the tentative nature of scientific knowledge. Although she clearly stated that scientific knowledge (including both theories and laws) changes over time, her insistence on the discovery of scientific knowledge, rather than creation of explanations, indicates a contradiction in her framework. If science is a process of uncovering extant explanations, at some point we should expect those explanations to be stable. However, this intermingling of science and religion is not complete as Donna was able to clearly relate how, unlike religion, science uses empirical evidence to repeatedly test existing theories and conceptions. She also found it useful to compare science and pseudoscience along similar lines, seeing the value of science literacy in making an individual a more alert and savvy consumer. She distinguished science as an area of inquiry that is distinct from religion/faith via testability; however, she did view science as an activity that is subsumed by religion.

TABLE 4
Overview of Participants' NOS Conceptual Frameworks

NOS Concept	Donna	Sarah	Meagan	Lisa	John
Empirical	Moderate sophistication	Strong sophistication	Strong sophistication	Moderate sophistication	Strong sophistication
Evidence vs. explanation	Weak sophistication	Weak sophistication	Moderate sophistication	Weak sophistication	Strong sophistication
Theory vs. law	Weak sophistication	Weak sophistication	Weak sophistication	Weak sophistication	Strong sophistication
Theory-laden	Weak sophistication	Weak sophistication	Moderate sophistication	Moderate sophistication	Strong sophistication
Creative and imaginative	Weak sophistication	Strong sophistication	Weak sophistication	Weak sophistication	Strong sophistication
Tentativeness of scientific knowledge	Weak sophistication	Strong sophistication	Weak sophistication	Moderate sophistication	Strong sophistication
Sociocultural embeddedness	Weak sophistication	Moderate sophistication	Moderate sophistication	Weak sophistication	Strong sophistication
Bounded	Weak sophistication	Moderate sophistication	Strong sophistication	Weak sophistication	Strong sophistication

The Interaction of Conceptual Ecology and Conceptual Framework for NOS. In light of her reductionist view of teaching science content, it was not surprising that Donna seldom moved beyond a rather reductionist, definition-style approach to discussing the specific NOS components. However, her compartmentalized descriptions of NOS demonstrated the high degree of intelligibility Donna had for these NOS conceptions, as she was able to isolate and define each major aspect of NOS. Thus, her approach within this arena was highly pragmatic and served to fulfill the basic requirements for the course.

However, Donna did not elaborate to any extent on the nuances or interconnectedness of the NOS facets, keeping her consideration of these things on a superficial and segregated level. Her disposition to rely on external authority was reflected in her heavy use of quotes from the literature in her writing and her production of "correct" definitions in bulleted form. This reference to NOS authority combined with her views of the enterprise of science (as entirely characterized by its products) to allow her to understand the NOS facets as another group of distinct products, discrete bits of content to be transmitted via her science teaching. In Donna we have personified the distinction voiced by Elby and Hammer (2001), that a student's views can be productive (in this case allowing Donna to engage with the wide range of course materials), but not correct (or sophisticated in epistemological terms). Where we might differ with Elby and Hammer's argument, however, is that Donna's conceptual ecology was productive in terms of allowing her to arrive at intelligibility of many NOS concepts while it prevented her from arriving at the plausibility or fruitfulness of these concepts. Thus, components of her conceptual ecology were productive, but only in basic terms.

What was fascinating about Donna was the contradictions in her case study. While she worked to convey the strict meaning of the NOS conceptions (using her reductionist approach to learning and to science), she also explicitly conveyed her resistance to the image of NOS portrayed in the course, as shown in the following quote in which she discusses her approach in the NOS course: "I refuse to [focus] on something . . . that can't be agreed upon." Thus, we see much of her resistance to NOS discussion came from the tentative, uncertain, ambiguous nature of these discussions. While she was comfortable with intelligibility of NOS concepts, she continued to reject the plausibility of NOS ideas to explain science and to reject the fruitfulness of these ideas for her own science teaching. Thus, in conceptual *change* terms, Donna was not dissatisfied with her prior understandings and did not exchange her own framework for the "sophisticated" portrayal of NOS seen in the course. Thus, she did not experience wholesale conceptual change. However, as the data demonstrate, Donna's conceptual framework was expanded as she successfully struggled with the intelligibility of conceptions. Donna approached the course as "a game to be played" and she played that game well; however, Donna did not experience all the requirements for the wholesale change of conceptions.

What might have prevented this change? In light of her limited open-mindedness and strong resistance to ambiguity, she found the current debates/discussions within the NOS literature to be frustrating and a poor investment of energy for her or any classroom teacher. Thus, Donna did not problematize her current teaching practice through her exploration of NOS; the first requirement of the CCM, the sense of dissatisfaction with current conceptions, was not met for Donna. In light of her high degree of self-efficacy about her own teaching, limited amount of reflection upon her current practice, and scant dissatisfaction, NOS held minimal import for Donna in terms of classroom fruitfulness.

We want to leave the reader with the recognition that Donna's conception of science as a subset of religion, and her own strong religions beliefs, influenced the structure of her NOS framework predominately through the vehicles of her learning dispositions. We understand her difficulty to go beyond the intelligibility of NOS to be more related with her disdain for ambiguity, not because she held strong religious views. Although those learning dispositions may interact with some aspect of her religious worldview, it was her learning dispositions and not her religious views that influenced the manner in which she engaged with the material and the structure of her NOS conceptual framework. Thus, Donna's case demonstrates that although religious views were originally included as potential initial members of the conceptual ecology for NOS, these views did not hold the explanatory power for the structure of Donna's conceptual framework seen for learning dispositions.

Megan: Struggling to Make Sense of Science as Classroom Process

Megan taught first grade and was pursuing a master's degree in education during the time of this study. She embraced her position as a primary grade teacher, as she perceived it as fundamentally important and both emotionally and cognitively engaging. Although she had the scant formal science background found in many early childhood programs, she had a wealth of informal science experience that she valued and drew upon to inform her teaching.

NOS Conceptual Ecology. We understood Megan to have a constellation of affect and learning dispositions that allowed her to grapple with initial intelligibility with the nature of science. (See Table 3 for a summary of Megan's conceptual ecology for NOS.) Her constellation of learning dispositions included the following:

- A high self-efficacy for science coupled with a high efficacy for teaching.
- A comfort with ambiguity within NOS discussions, coupled with her limited need for an external authority, and an overall open-mindedness.
- Megan was highly reflective when considering NOS, often pausing to look back on what she knew in relation to what she was learning. She had a high need for cognition in this domain.

In addition to these learning dispositions, she understood all students to be capable, even of learning some aspects of the NOS (theories/laws, tentativeness) in the first grade. Megan understood the goal of all education, but particularly in science education, is to help students become independent thinkers who know how to ask questions. This goal for teaching science fit well with her understandings of science as a means to generate and answer questions. She understood science in largely process terms. When this process orientation was combined with her goal for education, and her notion that all learners are capable, it is not surprising that she saw direct applications of the content of this course in her own first-grade classroom. Indeed, after the course, she had developed two NOS units for her first graders.

NOS Conceptual Framework. Megan emerged from the course with a sophisticated understanding of the NOS canon. (See Table 4 for a summary of Megan's conceptual framework for NOS.) She successfully demonstrated knowledge of the empirical nature of scientific work, as well as the transition processes from observation/evidence to inference/explanation. In addition, she was able to convey an understanding of the generative role of theories, the sociocultural embeddedness of science, as well creative nature of scientific knowledge.

Megan's only area of weaker sophistication centered on tentativeness and distinctions of theory and laws. Although she could explain that science is not static, there were instances in which her discussions of the science enterprise contradicted this notion. One can see her struggles to understand tentativeness through her misconception concerning the hierarchy of theories and laws. This view was seen in her work and course interactions in early stages of the course, and later she modified this misconception. But even after this modification, there remain certain aspects of her work and interview that point to a weak understanding of the processes of change. In particular, she remained uncertain as to whether scientific knowledge is created or discovered. The language that she used to discuss the products of science often center on "proving" and "truth." She understood that change in scientific knowledge exists, but her understanding of that change centered on issues of its sociocultural embeddedness, with absolute, knowable truths still playing a role in her thinking. Thus, in her framework we see a contradiction between a learner who can understand the inferential leap needed from evidence to explanation, and one who still holds to an absolutist notion of knowledge. Perhaps, this was because the internal, more collective, practices of change (testability, falsifiability, consensus, peer review, etc.) were minimized by Megan in light of an emphasis on individual subjectivity, persistence, and engagement with scientific questioning.

In terms of the bounded nature of science, Megan saw science as *a* way of knowing, not *the* way; she emphatically explained that science could not answer all. She made clear distinctions between science and religion being specific ways of knowing, indicating that religion does not use science's notion of testability. Her goal was for both science and religion to coexist as legitimate means of knowing for students, drawing on her own prior tensions and her belief that religion is comforting and gives purpose to life.

Interaction of Components of Conceptual Ecology. Megan was stronger in emphasizing process over product in her thoughts about science and science teaching, a point that may be linked to her views on tentativeness. Since she understood science in terms of school science (which for her is all about process), theoretical or philosophical considerations of production of knowledge within science played a less central role in shaping her conceptual framework. In light of her championing process over product and her belief that all of her first-grade students are extremely capable of "doing" science (very student-centered goals), there was a need for her to focus most of her attention on the sociocultural, creative, and theory-laden NOS aspects. She felt the strong drive to "get all that down pat," rather than hammering out the nuances of NOS as these are facets that centered on questioning and personal sense making that were more transportable in her classroom. In light of this, the subjective nature of scientific work was fleshed out to a strong degree of intelligibility, but other veins of NOS are less fully constructed. Her process orientation and conception of teaching and learning kept her from seeing the role of products of science, other than the fact that students can construct them. Although she excelled in seeing creativity/imagination, theory-laden, and sociocultural embeddedness (as these constructs are closely linked to process), the notion of tentativeness was also linked to the products of science (something she overlooked) and so this aspect of her NOS framework fails to fully develop.

Her goal was for both science and religion to coexist as legitimate for students, drawing on her own prior tensions with what science can and cannot account for. She understood religion as comforting and she explained that it provided purpose to her own life, but her open-mindedness allowed science and religion to be collateral ways of knowing. Her need for cognition in terms of NOS not only added to her enthusiastic engagement with the content but also strengthened her resolve to better understand the bounded nature of science itself.

John: A Wonderer Aware of Something Beyond the Classroom

At the time of the course, John already had his physics and chemistry teaching credentials for high school. However, he spent the previous year teaching 8th grade integrated science and enjoying it much more than he had anticipated. During this course, John positioned himself as a teacher successfully struggling to make sense of this material in terms of the classroom. However, this positioning was combined with his obvious engagement with the material on a theoretical level, as he worked to participate in the academic, scholarly discourse. Thus, he also positioned himself as a scholar apprentice to the course instructor.

NOS Conceptual Ecology. Much like Megan, we understand John to have a constellation of affect and learning dispositions that allowed him to enthusiastically grapple with the nature of science, and in his case to a very profound level. (See Table 3 for a summary of John's conceptual ecology for NOS.) His constellation of learning dispositions included the following:

- A high self-efficacy for both science and teaching.
- A comfort with ambiguity within NOS discussions, coupled with a limited need for an external authority, and an overall open-mindedness.
- Like Megan, in this domain, John was highly reflective, often pausing to look back on what he knew in relation to what he was learning. He had a very obvious high need for cognition in this domain, pausing frequently to analyze, debate, and expand on an idea with the instructor or with other class members.

Unlike the other learners in our study, John was engaged in another activity aside from honing teaching skills, namely his apprenticeship as a scholar. It was obvious throughout the course that he was attempting to enter the academic conversation regarding NOS and its intersections with science teaching, and this engagement allowed him to struggle with the material on a profound level.

In addition to these learning dispositions, he understood all students to be very capable, even though he understood the process of learning in general (and the learning of NOS specifically) to be very difficult and complex. Because given this complexity, he understood that teachers must use a great deal of care in crafting instruction, and on this point he was more explicit than the others in the group. Also, unlike the others, John was the only teacher in our group who understood the enterprise of science in both process and product terms, giving equal weight and attention to both.

NOS Conceptual Ecology. Overall, John held a very strong level of sophistication for all of the targeted NOS components. (See Table 4 for a summary of John's conceptual framework for NOS.) This was evidenced not only through his detailed discussion of each individual tenet of NOS but also through the way he worked to show how those tenets were interconnected and interdependent. For example, he related how seeing scientific knowledge as a discovery, instead of a creation, would be in conflict with a robust understanding of tentativeness. In terms of creativity, he recognized its influence extending throughout the entire scientific process. He spoke of creativity not only in terms of initial interests and insightful approaches but also in the very act of creating explanations from evidence, thus implicating creativity within the move from observation to inference. His work and discussions reflected a strong understanding of sociocultural aspects of NOS, both in terms of the language and cultural practices of science itself, as well as the external influences of the societies in which it is practiced. John also demonstrated a balanced and robust understanding of both tentativeness and durability, explicating how those two concepts were driven both by the practices of scientists as well as by theoretical presuppositions that scientists hold concerning the goals of science. This is something that also marked him as unique among the participants.

John understood both science and religion as being distinct ways of knowing. He viewed them as being able to coexist harmoniously within an individual, an state that one can more easily attain via a stronger NOS understanding. He explained how both science and religion hold distinct viewpoints concerning how to interpret the natural world, noting the limitations of each epistemology particularly in terms of the methodological assumptions of science. He also expressed how the functions of testability and falsifiability were central in understanding the bounded nature of science.

Interaction of Components of Conceptual Ecology. John reflected a high efficacy in terms of science and teaching, a need for cognition, and a motivation to participate in a different discursive practice than the other participants. He used NOS to position himself as a scholar, someone different from his peers, although he actively worked throughout the course to support the learning of everyone in the class. Being especially reflective about both NOS and its intersection with his teaching practices facilitated John's high degree of engagement with the material.

Since John saw learners as capable, and he saw that there was a very useful role for NOS in the classroom, he not only deals with intelligibility but also with plausibility and fruitfulness. While each of the participants, to some degree, engaged in conversations concerning application, John's thoughts about classroom fruitfulness of NOS did not overshadow or limit his grappling with the nuances of individual NOS components.

Although we have seen a focus on science as process paralleling a less rich understanding of tentativeness and/or durability in other participants, such as Megan, this was not so with John. His conceptualization of science as both process and product facilitated his discussion of tentativeness both in terms of change over time as well as a theoretical presupposition concerning the repudiation of absolute truths. His engagement with the NOS components as a means to position himself within academia pushed him toward thinking about NOS in ways that were not limited to describing NOS for the purposes of the course requirements or for debating its usefulness within his immediate classroom context. Indeed, his comfort with ambiguity was reflected in his joining the conversations in the literature concerning NOS. Unlike Donna, John's approach to NOS was very holistic and he did not discuss NOS as compartmentalized, discrete bits of information. Rather, he successfully demonstrated how the tenets function together to create a more sophisticated approach to learning science. This robust understanding of the interconnected nature of the pieces of the NOS canon combined with his high level of open-mindedness and his limited need for external authority to successfully bind science as a unique way of knowing.

CROSS CASE ANALYSIS AND DISCUSSION

We looked across the three cases (Donna, Megan, and John), as well as two others (Sara and Lisa) that were not reported in detail, to determine what commonalities existed for these practicing teachers as we compared conceptual frameworks with their conceptual ecologies for NOS. (See Tables 3 and 4 for summaries from all five participants).

We understand a teacher's degree of intelligibility for aspects of NOS to be shaped by her/his learning dispositions. As suggested by other researchers and by descriptions of effective NOS instruction, certain degrees of reflection and need for cognition in this domain play a role in supporting teachers in their efforts to find NOS intelligible. This echoes the findings of Abd-El-Khalick and Akerson (2004) in their study of preservice teachers, who describe that students who had a deep processing orientation (allowed for by reflection and need for cognition) were more likely to construct more sophisticated NOS views. This discussion becomes more complex as we consider that a teacher's disposition of intolerance of ambiguity and need for external authority would also influence their evaluation of the plausibility and fruitfulness of NOS. Clearly, Donna's disdain of ambiguity and need for a clear authority (in light of the complex and sometimes ambiguous nature of NOS discussion) played a role in halting her further consideration of NOS past anything necessary for minimum course requirements.

The majority of the push toward consideration of the fruitfulness of NOS views for the classroom was shaped by the teachers' views of learning and their perceptions of the capabilities of their students interacting with their views of science as an enterprise. That is, if teachers saw their learners as capable and learning to be a difficult but achievable process of construction, then they were much more likely to move toward recognition of the fruitfulness of NOS in their classrooms. This was true for the participants who had a strong process conception of the enterprise of science (Sarah, Megan), as well as for the single teacher who had a hybrid conception of science (John). However, if teachers understood their students to be fundamentally incapable and learning to be difficult and largely a process of reception of information, and if they understood science to be largely about the products of science, then they failed to grapple with the fruitfulness of NOS for their teaching. This relation between the nature of science, the nature of learning, and the nature of teaching has also been described by Tsai (2002) and our participants show how these factors interact to shape the teachers' NOS framework.

Also, echoing the work of Abd-El-Khalick and Akerson (2004), we found that deep consideration of the entire NOS framework is linked to the teachers' conceptions of science as product, process, or a blend of the two. To recognize this interaction, we focused on the cases of Megan and Lisa who understood science only in terms of process, and thus failed to fully engage in aspects of the NOS framework that are more closely tied to the products of science. Conversely, John's deep engagement in a wide range of the NOS canon was allowed by his emphasis on science as both process and product.

Our findings also suggest that consideration of intelligibility, plausibility, and fruitfulness does not play out in the rational order we often expect in light of conceptual change theory. Within the bulk of conceptual change research, one expects that only after a learner finds an idea intelligible would she move onto consideration of the reasonableness of the idea in light of other knowledge (plausibility). If this requirement is satisfied, then the learner would go on to consider the fruitfulness of the idea for solving new problems. However, our data did not support this rational, logical pattern described in the literature. Indeed, Lisa and Megan who were so driven to apply these new ideas in the classroom, struggled with intelligibility, but then quickly leapt toward considerations of the fruitfulness of the construct for their own teaching. The plausibility of the construct in light of their other knowledge was not considered. Again, we are reminded that descriptive accounts of what students know and how they learn do not always support the logical, rationale account of knowledge construction suggested by the original CCM and its applications. Here, we see how motivational, affective factors shape how a learner engages with material.

Focusing on the influence of religion was not productive for us to understand the conceptual frameworks for these five teachers. Instead, other learning dispositions, such as need for a single right answer and comfort with ambiguity (Erwin, 1983) and epistemological belief in the need for a single authority (Schommer, 1990), both potentially linked to some forms of religious beliefs, were far more powerful in explaining the teachers' NOS conceptual frameworks than the teachers' religious beliefs themselves. As suggested by Abd-El-Khalick and Akerson (2004), this aspect of the students' cultural knowledge and beliefs may exert influence in shaping NOS frameworks, but we argue these beliefs are mediated through the actions of related learning dispositions. Thus, the content of the learner's religious belief may not be as important as what learning dispositions these beliefs *may* be combined with (Sinatra et al., 2003). Given the very mediated nature of the potential influence of religious beliefs and the weak utility they held in explaining our data, participants' religious beliefs were, ultimately, not included in their conceptual ecologies. We understand religion not as a central agent in a conceptual ecology, but rather with dispositions filling that role.

This discussion is complicated, however both by our participants and their instructional context. Each of the five participants selected were strongly religious, meaning religious views were important aspects of their belief system and shaped many of their personal activities. Indeed, at the outset of the study we hoped that such strongly religious participants would help us better understand the role religious beliefs play in the conceptual ecology for NOS. However, we must be mindful to the instructional context: it was one in which the bounded nature of science, the distinction between science and other ways of knowing, was emphasized. Thus, religious views may not have been prominent "players" in the conceptual ecology due to the manner in which course instruction provided learners "with a place to stand" while comparing competing knowledge frameworks (Scharmann, 1990).

Our data demonstrate that affect for science, past science experiences, and learning goals to be secondary influences in shaping participants' NOS conceptual frameworks. These serve to influence NOS frameworks in conjunction with the primary influences of the learning dispositions, the conceptions of learning science and learner's capabilities, and views of science as an enterprise. Our research contributes to the work of Abd-El-Khalick and Akerson (2004) in continuing to describe the role of the rational and extrarational in learning NOS constructs.

CONCLUSIONS AND IMPLICATIONS

With the work of Strike and Posner (1992) and Pintrich et al. (1993), we have understood conceptual change as a potentially "hot" process, as affect, goals, motivation, and beliefs gained new salience in descriptions of learning. However, although these constructs as well as others are recognized to be potentially influential, much remains to be done in terms of understanding the actual nature of that influence, a call our work was designed to answer. Drawing heavily on descriptions of a model of conceptual change proposed by Dole and Sinatra (1998), we understand a number of learning dispositions and related personal epistemological beliefs to shape how teachers engage with NOS tenets, an engagement that has direct implications for the status of these ideas for the teachers. We understand teachers' beliefs about learning and learners (their recognition of the capabilities of students and the difficulty of learning) to combine with their overall ideas of science as an enterprise to shape how they address considerations of NOS tenets.

We understand a learner's past science experiences, her goals for learning, as well as her emotions regarding science to play a role in the conceptual ecologies; yet, this role is meditated through learning dispositions as they influence the way the learner engages with the material. For instance, as described by Sinatra (2005), students who approach learning with the goal of mastering content engage in deep processing of material. Conversely, students who approach learning with a performance goal orientation of completing the course or achievement of grades more superficially engage in the material and more superficially reconstruct their NOS frameworks. This echoes the work of Abd-El-Khalick and Akerson (2004) in their description of the importance of a "deep" approach to the material for preservice science teachers, although we found this deep approach and perception of utility to be achieved through particular learning dispositions. Although these authors found the learners' perceptions of the utility of NOS for their future classrooms to be a very significant influence, this is replaced in our practicing teachers with their perceptions of learning and their assessment of the capabilities of their learners. This shift between preservice and inservice does resonate, as these practicing teachers had actual students to consider as they approached the consideration of NOS, while for the preservice teachers these concrete experiences are not yet available.

What is *not* included in our results is as informative as what *is*. In this work, we did not find specific religious beliefs to be a factor in the conceptualizing of the NOS. Echoing the findings of Abd-El-Khalick and Akerson (2004), learners who have religious beliefs were capable of constructing a relatively sophisticated understanding of the nature of science. However, learning dispositions and epistemic beliefs (such as comfort with ambiguity, need for an outside authority) that are sometimes associated with some religious beliefs did act to limit the conceptualization of NOS of some of our participants. Thus, we describe that particular learning dispositions were far more influential on participants' NOS frameworks than their religious beliefs. But we recognize that this may have been the case because the instructional context was one in which the learners were lead to a description of the bounded nature of scientific knowledge, boundaries established by the methodological assumptions of science in comparison to other knowledge frameworks. It may be the case that this instructional approach allowed for religious beliefs to "take a backseat" to learning dispositions for these learners.

We argue that the complex and visceral ties between NOS conceptions and goals, affect, dispositions, belief, etc. speak to the inclusion of the bounded nature of science as a central aspect of NOS frameworks for practicing teachers. Teachers' conceptions of the boundaries of science are, for some, intimately linked to their dispositions toward learning this construct, as well as their understanding of the role of NOS in their own teaching. Thus, while the bounded nature of science has not come out of the consensus of NOS discussion, we argue that it is fundamentally important in describing how teachers come to understand the rest of NOS and how they approach it in terms of their own teaching.

Alsop (2005) and others urge educators to design instruction with extrarational factors in mind. It is clear that we must be mindful of the entirety of the NOS conceptual ecology as we approach our teachers. Although each of the central tenets of NOS is important, we urge that particular care should be taken to help teachers understand the bounded nature of science, as much of the affective dimensions of NOS are tied to this construct. Indeed, we argue that the bounded nature of science is like the other NOS concepts, in that it too is a cognitive outcome. However, it is a conception heavily influenced by the affective, and so requires particular care as its instruction is approached.

Finally, Sinatra and Pintrich's (2003) work in intentional conceptual change suggests that making learners aware of the influence of affect, motivation, and learning dispositions can allow them a metacognitive awareness needed to more effectively engage in material. Application of the intentional conceptual change discussion in this domain suggests that if a teacher understands that her need for authority or rejection of ambiguity may be limiting her consideration of NOS material, this awareness may prove instrumental in reshaping her approach to course content. When emotion, goals, dispositions are brought into conscious attention, Sinatra and Pintrich suggest that *they can be used intentionally* by the learner to attain learning outcomes. Thus, close consideration of components of a conceptual ecology may prove useful in shaping "what gets talked about" in NOS curriculum.

APPENDIX A: DESCRIPTION OF NATURE OF SCIENCE COURSE

Session	Reading Topics	Class Activities	Overarching Topics
1		• Course introduction; why are you here?	The purpose of science and science education.
		• What is the purpose of science education? • Bubble observation.	The nature of observation.
2	The purpose and domain of scientific inquiry.	• Bubbles in review.	The definition of "science" and its disciplines.
	The "scientific method."	• What is science? The question of "Umbrellaology" (Smith & Scharmann, 1999; Sommerville, 1941). • The "scientific method." • Discuss VNOS and STILT. • The madness of stirring hot chocolate (an inquiry into pitch change of stirred mixtures)	The nature of questioning, scientific method.
3	Fact, law, and theory descriptions and distinctions.	• Discuss: Fact, law, and theory.	Evidence vs. explanation and the multiplicity of levels within scientific knowledge.
		• History of science: The facts, laws, and theories of our solar system.	
4	Demarcations definitions of science.	• What is the nature of science?	Demarcation of science.
		• Card sort (Gess-Newsome, 2002). The roles of language in describing scientific processes.	Science as a way of knowing.
5	"Change" and "shift" in science.	• Discuss: The tentative nature of science.	The tentative nature of science.
		• Critical incidents: Experiment (e.g., "What would you do if this experiment went wrong in your classroom. . . "). • The swinging pendulum: History and experiment.	Scientific knowledge changes.

Continued

APPENDIX A: DESCRIPTION OF NATURE OF SCIENCE COURSE
(Continued)

Session	Reading Topics	Class Activities	Overarching Topics
6	"Change" in science; "discovery" vs. "creativity" in science.	• Debrief "tentativeness" and "durability"	The tentative and durable nature of scientific knowledge.
		• Pseudoscience lab	Science vs. pseudoscience.
		• Intro: What do students understand about the nature of science?	
7	NOS understandings of students and teachers.	• Finish pseudoscience.	Science vs. pseudoscience.
		• "What do students/teachers understand about the nature of science and why does it matter?"	The role of NOS understandings in science literacy.
		• Critical incidents: Knowledge (e.g., "what would you do if this piece of scientific knowledge were challenged by a student/parent. . . ").	
8	NOS understandings of students and teachers.	• What do teachers understand about the nature of science?	Explicit vs. implicit vs. historical treatments of the NOS in the classroom.
	NOS pedagogy	• What should science instruction look like?	
9	Science and religion	• What is the "way of knowing" of science?	Science and religion.
		• "Whiteman's Witchcraft" and the Kennewick Man: Discussions of potential conflicts between science and religion.	Science as a way of knowing.
10		Exit interviews	The grand synthesis of NOS understanding, pedagogy, and teacher specific strategies.

APPENDIX B: WRITING ASSIGNMENTS FOR COURSE: DATA COLLECTION TOOLS FOR RESEARCH

Session	Writing Assignment, Data Collection Tools
1	Course introductions: Description of each student's educational background and teaching assignment.
2	VNOS (Lederman et al., 2002) STILT (Southerland et al., 2003b)
3	**Response Paper 1** What is the difference between a scientific "fact," "law," and "theory"? How do these interact with one another? Why is it important to understand this, and how does/should this be represented in the classroom? Email response: Is umbrellaology a science?
5	**Response Paper 2** What does it mean for science to be "tentative" or "changeable"? What examples can you describe for this? Why is this important for students to know; and how can this be portrayed in the classroom?
6	**Response Paper 3** Students were to pursue an alleged pseudoscience of their choosing, and then research the pseudoscience in order to evaluate the degree to which it was scientific.
7	**Response Paper 4** What kinds of understandings of the nature of science should you expect your students to have? What are you going to do about it? Why?
9	**Response Paper 5: Science and Religion** Compare science and religion. Specifically, how does science come to understand the world, and how does religion come to understand the world—are these views compatible? Why is this important for science education? How should this be portrayed in the classroom? **Revisiting VNOS and STILT** **"Prelude to the Final" Assignment** Sometime before the next class, send an email to [the course instructor] that answers the following questions. These are meant to be things to think about as you begin to draft your final. It will also be used as things for the friendly yet critical instructor to think about as he reads and grades your final. 1. Briefly describe your own science background. Have you been encouraged or alienated by science? What science coursework has contributed to this (consider all grades, elementary through graduate school)? 2. What/who do you teach? What are your own objectives as a teacher of science? (Yes, you are teaching science, whether it's explicit or not.) Explain who your students are, what you believe they can learn, and what you believe they need to learn. 3. Imagine that you are enrolled in a science course that you've never taken before and has material that is completely new to you; perhaps it's "Astrobiology, ZOOL 3620" or something like this. How would you feel about taking such a course? How confident are you yourself in your ability to learn the material in such a course? What would you *want* to learn from such a course?

Continued

APPENDIX B: WRITING ASSIGNMENTS FOR COURSE: DATA COLLECTION TOOLS FOR RESEARCH *(Continued)*

Session	Writing Assignment, Data Collection Tools
	4. In general, what does it really mean to "learn" or "understand" something? In other words, what do you expect a student (or yourself) to be able to do/write/express in order to show that something has been learned/understood? Spend some time reflecting on this, and save a copy for yourself. This is meant to be a first step in developing your ideas and arguments in the final paper. In fact, it would be completely fair game to copy and paste anything out of this assignment right into your final paper. (In case you haven't noticed yet, this is a particularly useful strategy in graduate school.)
10	**Final Paper** The final paper was meant to "be a synthesis of the entire class, what you've learned from it, and how you propose to incorporate nature of science learning in your classroom. This should be a formally written paper, but it will rely upon your own reflection. You should cite readings from the course, class discussions, and your own response papers and other activities from the class." Specifically, this final synthesizing assignment asked students to address the following questions: 1. What, in your view, is the nature of science? How has your conception changed? 2. What aspects of the nature of science should a "scientifically literate" citizen know? Why? 3. What aspects of the nature of science should be emphasized in *your* classroom? Why? (This answer should be tied to your answer to #2.) 4. How can the nature of science be most effectively taught in *your* classroom? Justify your ideas. (This answer should be tied to your answer to #3.)
11	**Exit Interview** Each student was required to have an individual "class session" with the course instructor at the student's convenience. This exit interview consisted of a debriefing of the student's final paper and her/his work in the course. Pedagogically speaking, the intentions were pure: The instructor wished to actually interact with students after the "final" paper had been turned in, in order to ask final questions and have the paper actually mean something in the long run. This particular strategy was additionally useful for research purposes, as it gave a final opportunity to really engage the students in "what did you mean by that?" clarifications (Southerland, Smith, & Cummins, 2000). The questions asked of each interviewee were catered to the student's paper, its points, and questions it raised. In this way, each interview was different, but the goal of each interview was to clarify each student's thinking (both to the instructor and to the student herself). Additionally, this served as a tool to try to further elicit the student's own goals in the classroom, how the NOS fit into these, and how the course enabled and/or influenced such goals. In this manner, the interviews provided an in-depth course evaluation.

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