RESEARCH AS AN INSTRUMENT FOR CHANGE: EXAMINING THE IMPACT OF RESEARCH EXPERIENCES ON TEACHERS' CONCEPTIONS AND TEACHING OF THE NATURE OF SCIENCE

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CHAPTER I

INTRODUCTION

The science education community considers developing students' scientific literacy a primary goal of K-12 education. Accordingly, science education reform documents generated over the past 20 years call for the development of students' scientific literacy across all grades of schooling. The definitions of scientific literacy put forth in these reform documents lack consistency, however. For example, the *National Science Education Standards* (National Research Council [NRC], 1996) defines scientific literacy as "the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity" (p. 22). In contrast, the *Atlas of Science Literacy* (American Association for the Advancement of Science [AAAS], 2001) proposes that students should acquire "a basic understanding of the natural and social sciences, mathematics, technology, and their interactions" (p. 3) to achieve scientific literacy. Although a consensus has not yet been reached on the meaning of this phrase (DeBoer, 2000), one aspect of scientific literacy is common to most descriptions: an understanding of the *nature of science* (NOS).

The *National Science Education Standards* (NRC, 1996) claims that an understanding of NOS is necessary for developing students' scientific literacy and notes that scientifically literate individuals should be able to evaluate scientific issues and information based on their understanding of the enterprise of science. Individuals' reasoning about science-related issues should be based on an appreciation for the methods and processes of science, including how arguments are formed and conclusions are reached in various scientific domains. Similarly, the *Atlas of Science Literacy* (AAAS, 2001), as well as the *Benchmarks for Science Literacy* (AAAS, 1993) on which the *Atlas* is based, emphasizes the importance of teaching about NOS. Like the *Standards*, the *Atlas* stresses the value of understanding the methods and processes of science, and additionally the sociocultural aspects of scientific practice, for the development of students' scientific literacy.

While the need for a deep understanding of NOS, as called for in reform documents such as the *Standards* (NRC, 1996) and *Atlas* (AAAS, 2001), may be viewed as valuable only to those within the science community, it is also necessary for individuals outside the field. Individuals will likely be confronted with a variety of scientific issues throughout their lifetime, regardless of their chosen profession, such as when making decisions about medical treatment or evaluating the impact of their actions on the environment. Most recently, the *Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012) put forth the following goal for students' K-12 science education:

> to ensure that by the end of 12th grade, *all* students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the

> skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology. (p. 1)

Without an understanding of NOS, individuals cannot understand how scientific theories are developed and refined, and they consequently cannot adequately reason about the construction and validity of the scientific arguments they encounter in everyday life. Therefore, given the importance of the development of adequate conceptions of NOS for all individuals, it is imperative that a comprehensive definition of NOS be established so that science educators can work toward achieving a common goal.

Unfortunately, like scientific literacy, consensus on the definition of NOS does not yet exist. Science education researchers' efforts to conceptualize NOS have yielded a plethora of descriptions of this phrase that vary in their inclusiveness. I therefore begin the second chapter of this dissertation by reviewing the different ways in which science education research literature has conceptualized NOS, highlighting the differences in the scope of the descriptions provided in this work, as well as points of overlap and divergence in the researchers' definitions. I then draw upon perspectives grounded in the sociology and philosophy of science, as well as existing definitions of NOS in the science education literature, to generate a more authentic, domain-general NOS framework. Following the description of my NOS framework, I discuss the use of three theoretical lenses useful for considering how individuals, particularly teachers, might develop NOS understanding that more closely aligns with my aforementioned framework through engagement in authentic research experiences. Existing studies of programs designed to provide teachers with such research experiences are then described in order to highlight the need for the study on which I focus for this dissertation.

Building upon my NOS framework, the potential affordances of research experiences for the development of teachers' NOS understanding in alignment with my framework, and the constraints of past work related to teacher research experiences as described in Chapter II, I seek to determine to what extent participation in research might affect teachers' NOS understanding. I also investigate whether there are patterns evident in aspects of or activities within teachers' research experiences that suggest that they may help make certain aspects of NOS more salient to participants. Finally, I explore whether any changes take place in teachers' classroom instruction that reflect shifts in their NOS understanding. This study is situated in research experiences grounded in engineering, rather than science, and there are both similarities and differences between these two disciplines. Yet, experiences in engineering research may challenge several pre-existing ideas about science that teachers are likely to hold. For example, engineering, like many sciences, is highly interdisciplinary, tends to rely on a variety of methods (not just experimentation), and often is accomplished in collaborative teams. The program studied here was not designed explicitly to address the nature of science, but as I will explain, it afforded many opportunities for study participants to reflect about their notions of how science is conducted. A description of the study design intended to address these questions can be found in Chapter III, with results following in the fourth chapter. In my final chapter, I discuss the potential implications of my findings, particularly in relation to design of professional development programs that provide research experiences for teachers.

CHAPTER II

RECONCEPTUALIZING THE NATURE OF SCIENCE AND THE DEVELOPMENT OF NOS UNDERSTANDING

The importance placed on the development of students' understandings of NOS in the science education community necessitates a cohesive definition of this concept. As noted previously and described in detail below, a consensus on such a definition has not yet been established. Therefore, in the first part of this chapter I analyze and synthesize two different sets of literature (i.e., science education, as well as sociological and philosophical studies of science) in order to generate a comprehensive framework aimed at describing the scientific community of practice.

Given the value placed on students' understandings of NOS, once agreement is reached about what it entails (whether my framework or otherwise), it is important to consider how we might cultivate adequate and accurate conceptions of NOS in students. In his review of NOS studies, Lederman (1992) noted that existing research led to "the overwhelming conclusion that students did not possess adequate conceptions of the nature of science or scientific reasoning" (p. 335). Although the studies reviewed did not describe NOS in the same manner as my framework, it is reasonable to conclude that students' conceptions of NOS would not align with this framework, either, as it draws and expands upon existing descriptions of NOS. How, then, might we help students develop adequate conceptions of NOS that align with my framework?

To begin to respond to this concern, we must first take into account the parties responsible for helping students develop their NOS understanding. While students likely enter the classroom with some ideas about NOS based on prior experiences both in and out of school, as noted previously, science education reform documents such as the *National Science Education Standards* (NRC, 1996) and the *Atlas of Science Literacy* (AAAS, 2001) hold teachers responsible for this task. We must therefore reflect upon the extent to which teachers themselves are developing adequate conceptions of NOS and how they may go about doing so in order to be equipped to facilitate development of comparable NOS understanding in their students. As described in the second portion of this chapter, the work of Lave and Wenger (1991), Rogoff, Paradise, Arauz, Correa-Chavez, and Angelillo (2003), and Goodwin (1994) provide three unique, yet related, theoretical lenses through which teachers' NOS development may be considered. Each of these perspectives sheds light upon one potential pathway for the development of teachers' NOS understanding: participation in authentic research environments.

Upon establishing the potential value of teachers' participation in research as a means for advancing their NOS understanding, it is helpful to review previous work addressing opportunities for teacher engagement in research. The third segment of this chapter therefore describes the types of teacher research programs have already been examined through this work and to what extent. I point out several ways in which these studies could be expanded upon in order to gain further insight into their effectiveness in affecting change in teachers' NOS understanding, as well as their classroom instruction related to NOS. This chapter therefore concludes with a call for such investigation, underscored by a separate review of studies conducted by Sadler, Burgin, McKinney, and Ponjuan (2010), which I then address in my remaining chapters.

Describing the Nature of Science

In generating definitions of NOS, science education researchers have largely drawn upon aspects of NOS emphasized in reform documents such as the *Standards* (NRC, 1996) and *Atlas* (AAAS, 2001). However, two areas of research aimed at describing science as a discipline do not appear to have been taken into account when generating these reform documents and are also often overlooked by science education researchers: sociological and philosophical studies of science. Although the sociology and philosophy of science literatures do not directly offer alternative conceptions of NOS, the insight that these studies provide with regard to science research practices provides another lens for its consideration. Elements of scientific practice that are essentially invisible to outsiders (and sometimes insiders) are explored and highlighted in these sociological and philosophical studies. Aspects of NOS that have previously been overlooked by science education researchers therefore become more apparent in view of these studies of science. To date, some science education researchers have drawn upon sociological and philosophical studies of science when describing particular aspects of scientific practice that they view as valuable for science education. In spite of this, few connections have been made between science education and sociology and philosophy of science literatures in direct regard to NOS.

The problematic lack of consensus on an appropriate definition of NOS among science education researchers, which I will illustrate by laying out areas of overlap and divergence in existing definitions, suggests that further work is needed to reconceptualize NOS and develop a new definition for this idea. Furthermore, because sociological and philosophical studies of science have largely been ignored in the science education literature in relation to NOS and aspects of it revealed by these studies consequently remain absent from current definitions, it is worthwhile to consider the insights into scientific practice that might be gained from them. I therefore argue for and generate a more authentic, domain-general NOS framework by drawing upon current definitions in science education research literature and subsequently augmenting and refining them based on insights gained from sociological and philosophical studies of science.

Science Education Perspectives

As noted previously, the science education research community has generated a range of definitions of NOS that vary widely in their scope and specificity. Some researchers have laid out very precise, explicit conceptions of NOS that seem to consist of a collection of components, while definitions put forth by other researchers are relatively open-ended and framed by overarching principles. Consequently, different aspects of NOS are highlighted in each of these definitions, while others are deemphasized or altogether absent. Despite these differences, however, areas of overlap are apparent. These areas of overlap and divergence in existing definitions of NOS will be explored here, focusing on several researchers who exemplify their breadth of focus, in order to make evident the need to reconceptualize NOS. Table 1 provides an overview of the ideas put forth by the researchers addressed in this section and serves as a basis for the subsequent analysis.

Table 1

Overview of Components of NOS Definitions Described in Recent Science Education Research.

COMPONENTS OF NOS DEFINITIONS	**RESEARCHERS**		
	Lederman et al	**Kimball**	**Duschl et al**
Scientific Knowledge			
Tentative and therefore subject to change	X	X	
Draws upon a range of scientific methods	X		X
Empirically-based	X		
Observation of the natural world	X		
Inference about the natural world	X		
Question generation			X
Development of hypotheses			X
Data collection and analysis			X
Process-oriented		X	X
Product-oriented			
Socially-constructed			X
Interconnected among disciplines			X
Generated/built through justification of claims			X
Construction of claims/arguments			
Critique of claims/arguments			
Influences on Scientific Knowledge			
Science as a human endeavor based on	X	X	
Beliefs	X		
Creativity and curiosity	X	X	X
Theory- and/or Value-Laden	X	X	
Sociocultural	X		X
Historical			X
Goals of Science			
Provide a unique way of viewing the world			
Understand and explain the natural world		X	
Simplification of the natural world		X	
Modeling natural phenomena			
Problem solving			
Other			
Role(s) of Laws & Theories	X		
Definition based on input from			
Philosophy of science		X	X
Sociology of science			X
History of science			X

Table 1, continued

COMPONENTS OF NOS DEFINITIONS	**RESEARCHERS**	
	Driver et al	**Southerland et al**
Scientific Knowledge		
Tentative and therefore subject to change	X	
Draws upon a range of scientific methods		
Empirically-based	X	
Observation of the natural world	X	
Inference about the natural world	X	X
Question generation		
Development of hypotheses		
Data collection and analysis		
Process-oriented		X
Product-oriented		X
Socially-constructed	X	
Interconnected among disciplines		X
Generated/built through justification of claims		
Construction of claims/arguments		
Critique of claims/arguments		
Influences on Scientific Knowledge		
Science as a human endeavor based on		
Beliefs		
Creativity and curiosity		
Theory- and/or Value-Laden		
Sociocultural		
Historical		
Goals of Science		
Provide a unique way of viewing the world		X
Understand and explain the natural world		
Simplification of the natural world		
Modeling natural phenomena		
Problem solving		
Other		
Role(s) of Laws & Theories	X	X
Definition based on input from		
Philosophy of science		
Sociology of science		
History of science		

Table 1, continued

COMPONENTS OF NOS DEFINITIONS	**RESEARCHERS**	
	Rudolph & Stewart	**Ford**
Scientific Knowledge		
Tentative and therefore subject to change		
Draws upon a range of scientific methods	X	
Empirically-based		
Observation of the natural world	X	
Inference about the natural world		
Question generation		
Development of hypotheses		
Data collection and analysis		X
Process-oriented		
Product-oriented		
Socially-constructed		X
Interconnected among disciplines		
Generated/built through justification of claims		X
Construction of claims/arguments		X
Critique of claims/arguments		X
Influences on Scientific Knowledge		
Science as a human endeavor based on		
Beliefs		
Creativity and curiosity		
Theory- and/or Value-Laden	X	
Sociocultural		
Historical		
Goals of Science		
Provide a unique way of viewing the world		
Understand and explain the natural world		X
Simplification of the natural world		
Modeling natural phenomena	X	
Problem solving	X	
Other		
Role(s) of Laws & Theories		
Definition based on input from		
Philosophy of science	X	X
Sociology of science	X	X
History of science	X	X

NOS as an assortment of components. As noted previously, several science education researchers describe NOS in terms of a set of components, yet the extent to which their definitions treat these components as interrelated varies. While some researchers delineate NOS components as relatively independent entities, others describe their definitions' components and then tie them together in reference to a more unifying principle.

The compartmentalized approach: Components of NOS as discreet entities. Some researchers in science education have devoted a great deal of their attention to developing a conception of NOS aligned with the values of science education reform documents such as the *National Science Education Standards* (NRC, 1996) and the *Atlas of Science Literacy* (AAAS, 2001). Lederman, one of the most prolific NOS researchers, has primarily dedicated his research to developing a NOS framework closely linked to the conceptions of NOS suggested in these documents. Lederman's work in this field has been extensive, as he has worked both individually and with colleagues to review prior research related to NOS (Lederman, 1992), generate an evolving definition of NOS (see, for example, Lederman, 1992; Abd-El-Khalick, Bell, & Lederman, 1998; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002), explore the conceptions of NOS held by both teachers and students (see, for example, Lederman, 1986; Lederman & Zeidler, 1987; Bell, Lederman, & Abd-El-Khalick, 2000), and develop an assessment of individuals' understanding of NOS (Lederman et al., 2002). In a study conducted with Zeidler (Lederman & Zeidler, 1987), as well as in his review of studies related to students' and teachers' conceptions of NOS (Lederman, 1992), Lederman acknowledged that no one definition of NOS had previously been agreed upon within science education. Lederman and Zeidler (1987) proposed the following:

> The "nature of science" most commonly refers to the values and assumptions inherent to the development of scientific knowledge. For example, an individual's beliefs concerning whether scientific knowledge is amoral, tentative, empirically based, a product of human creativity, or parsimonious reflect that individual's conception of the nature of science. (p. 721)

Over time, Lederman and colleagues expanded upon and revised the aspects of NOS that they deemed most relevant for K-12 education. Therefore, in work conducted with Abd-El-Khalick and Bell (Abd-El-Khalick et al., 1998; Bell et al., 2000), Lederman shifted his focus to include modified aspects of NOS, specifically that scientific knowledge is tentative in nature, empirically-based, subjective or theory-laden, the product of human endeavors and creativity, and both culturally and socially situated. Furthermore, the authors stressed the need to draw distinctions between observation and inference, as well as the roles of theories and laws, when considering scientific information. Although Lederman and his colleagues acknowledged that these aspects of NOS are interconnected in some of their work (i.e., Bell et al., 2000), they failed to elaborate upon these associations. The authors also discussed NOS in comparison to the processes of science, which they defined as "activities related to the collection and interpretation of data, and the derivation of conclusions" (Abd-El-Khalick et al., 1998, p. 418). The authors claimed that, although related, NOS and science processes are actually two distinct concepts, as NOS deals more with the beliefs that drive the scientific enterprise as a whole, whereas science processes involve the activities associated with scientific research.

These claims were further expanded upon when Lederman and colleagues developed an assessment instrument for evaluating individuals' conceptions of NOS (Lederman et al., 2002). In addition to the aspects of NOS described in their earlier work (specifically, Abd-El-Khalick et al., 1998; Bell et al., 2000), the authors asserted that an individual possessing an accurate conception of NOS should understand that scientific investigations do not use a fixed scientific method, as is frequently portrayed in science textbooks and other curricular materials (Bauer, 1992). Consequently, when constructing their *Views on the Nature of Science* questionnaire (Lederman et al., 2002) based on a culmination of their conceptions of NOS, the authors attended to the following aspects of NOS: (1) the empirical nature of scientific knowledge, particularly observation, inference, and theoretical entities; (2) scientific theories and laws; (3) the creative and imaginative nature of scientific knowledge; (4) the theory-laden nature of scientific knowledge; (5) the social and cultural embeddedness of scientific knowledge; (6) the lack of a universal scientific method; and (7) the tentative nature of scientific knowledge.

It is worthwhile to note that the researchers essentially dismissed concerns put forth by philosophers and historians of science in developing their conception of NOS and stated:

> The disagreements that continue to exist among philosophers, historians, and science educators are far too abstract for K-12 students to understand and far too esoteric to be of immediate consequence to their daily lives. For example, the notion of whether there is an objective reality or only mental constructions is,

> perhaps, only of importance to the graduate student in philosophy. (Abd-El-Khalick et al., 1998, p. 418)

Although the authors acknowledged that some of the more general NOS-related issues raised by philosophers and historians of science are more aligned with the interests of science educators, they chose to focus on elements of NOS put forth in relevant science education reform documents when constructing their NOS definition. Not all science education researchers to develop detailed conceptions of NOS have chosen to preclude the influence of philosophers of science, however.

Unlike Lederman and his colleagues, Kimball (1968) intentionally turned to the ideas proposed by philosophers of science in order to generate what he viewed as a more complete conception of NOS. The author based this perspective on the hypothesis that philosophers of science maintain conceptions of NOS that differ from those held by both scientists and science educators, as philosophers have been engaged in the study of the structure of knowledge. Kimball therefore established eight assertions about NOS based on his studies of literature addressing the philosophy of science and NOS: (1) the role of curiosity in the enterprise of science; (2) the idea that science is process-oriented, which the author described as the idea that "in the search for knowledge, science . . . is a dynamic, ongoing activity rather than a static accumulation of knowledge" (p. 111); (3) the idea that science attempts to develop knowledge that is comprehensive yet also simplified (e.g., through mathematical representations of relationships); (4) the lack of a single, universal scientific method; (5) the value-laden nature of scientific methods; (6) the idea that science is a human endeavor; (7) the openness of science; and (8) the tentative nature of science.

Several similarities between Kimball's and Lederman and colleagues' conceptions of NOS are starkly apparent, particularly the idea that scientific knowledge is tentative, that no universal scientific method exists, and that values and theories influence the development of scientific knowledge, as do human factors such as curiosity and creativity. Despite these areas of overlap, however, each includes aspects of NOS that are unique to the views of the authors. Perhaps most notably, Lederman and colleagues stressed the sociocultural embeddedness of scientific knowledge, while Kimball's conception left this out. Furthermore, Kimball attended to the goals of science, particularly the development of knowledge that is both comprehensive and simplified, whereas Lederman failed to identify any goals specific to the field, including the value of minimalism. Regardless, neither author made an attempt to consider the ways in which the components of NOS that they identified were related to each other, nor did they link these components to any broader guiding principles. By failing to address these connections, the components of Lederman and colleagues' and Kimball's NOS definitions may be interpreted as functioning independently rather than as activities that, taken together, constitute the enterprise of science as a whole.

The bottom-up approach: Components of NOS as interconnected. Unlike Lederman and colleagues and Kimball, some science education researchers who put forth extensive NOS frameworks did make efforts to identify the ways in which the components of their framework were interrelated. Duschl and his colleagues did so, in part drawing upon literature in the sociological and philosophical studies of science. In spite of the overall lack of attention devoted to sociological and philosophical perspectives on science in the science education literature directly addressing NOS, Duschl (as well as a relatively small contingent of other researchers, including Kimball), have attempted to bridge this gap. In fact, both Duschl's independent work (specifically Duschl, 1988) and his work with colleagues (Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003) advocated drawing upon perspectives of science in several fields, including philosophers, historians, and sociologists of science, as well as scientists and science educators. Duschl's (1988) efforts to encourage a movement away from views of science as an absolute authority led him to identify several goals of science education that are related to NOS. In addition to identifying the need to help students understand the tentative nature of science, as also suggested by other researchers such as Lederman and Kimball, Duschl addressed the difference between the processes of knowledge generation and knowledge justification in science. Although related, Duschl specified that these two characterizations of science produce vastly different images of its activities, in that knowledge justification approaches emphasize the verification of existing scientific knowledge, while knowledge generation approaches focus on the means by which that knowledge develops. He suggested that familiarity with both of these processes is critical for understanding the practices of science and particularly "both why science believes what it does and how science has come to think that way" (p. 57). The author also emphasized the roles of sociocultural and historical influences on scientific knowledge and its development. These latter elements of NOS proposed by Duschl emerged from work conducted by sociologists and philosophers of science. He argued that, by attending to these components of scientific practice valued in sociological and philosophical studies of science, a less authoritative view of science would be communicated to students, thereby preventing them from viewing scientific knowledge as absolute and indisputable.

He claimed, therefore, that experts in fields such as history, philosophy, and sociology of science should be involved in curriculum development to ensure that these views be adequately conveyed to students.

In a related study (Osborne et al., 2003), Duschl and colleagues further drew upon the perspectives of individuals in philosophy, history and sociology of science, as well as practicing scientists and science educators, to determine the extent to which a consensus exists among these fields about what should be taught to students in science. After several iterations, their questionnaire yielded nine *ideas about science* that should be understood by students: (1) the scientific method and critical testing; (2) the role of creativity in science; (3) the historical development of scientific knowledge; (4) the role of questioning in science; (5) the diversity of scientific thinking and scientific methods; (6) the analysis and interpretation of data; (7) the idea of the certainty/tentativeness of scientific knowledge; (8) the processes of hypothesis generation and prediction; and (9) the roles of cooperation and collaboration in the development of scientific knowledge. In spite of the study participants' agreement on these overarching nine ideas, however, the degree of consensus on what, specifically, should be valued and taught within these themes varied. For example, in commenting on the diversity of scientific thinking and methods, some participants stressed that students should understand that scientific research does not follow a fixed method and that scientific investigations take many forms. In response to the same theme, however, other participants expressed that they believed that students should be explicitly taught about methods common to all science disciplines (e.g., observation and theory-building). The authors therefore acknowledged that the nine ideas described in their work were intended to act as a "summary [that] captured the essence of the intrinsic concepts" (p. 708). Although the authors did not specifically state that they proposed a definition of NOS, connections between these ideas about science and NOS are apparent, particularly in relation to the development and refinement of scientific knowledge.

The second, fifth, seventh, and ninth assertions put forth by Osborne et al. (2003) are clearly visible in other conceptions of NOS. Lederman and colleagues similarly stressed creativity in science, the lack of a universal scientific method, and the tentativeness of scientific knowledge. Likewise, Kimball (1968) addressed the view that a universal scientific method is not employed in scientific research, as well as issues related to the tentativeness of science. It is also useful to consider that several of the aspects described by Osborne et al. (2003), such as the scientific method and critical testing, science and questioning, analysis and interpretation of data, and hypothesis generation and prediction, might be collapsed and considered components of the processes of science as described by Lederman and colleagues.

One unique component of NOS described by Duschl and his colleagues in Osborne et al. (2003) is the understanding of the historical development of scientific knowledge. Although this development may be influenced by the sociocultural factors addressed by Lederman and his colleagues, here the authors specifically advocated the explicit teaching of the history of science, including sociocultural influences on the enterprise throughout history. The authors suggested that lessons addressing the historical development of scientific knowledge would lead to an improved understanding of how scientific practices have changed in response to surrounding contextual factors (e.g., infectious disease outbreaks or the space-race research agenda that emerged following the

Soviet launch of *Sputnik*) and consequently contributed to further developments in science. Interestingly, despite the authors' reliance upon input from sociologists and philosophers of science in developing their conceptions of NOS, they did not address insights that might be gained through inspection of studies of scientific practice conducted in these fields.

Regardless, Duschl and colleagues' broader focus on the development of scientific knowledge throughout their work suggests that they did not view the components of NOS that they identified as unrelated entities (as was the case in the work of Lederman and colleagues and Kimball), but instead believed these components to be tied together by their relations to the construction of scientific knowledge. They further suggested that "many aspects of the nature of science represented by the themes [described in their work] have features that are interrelated and cannot be taught independently of each other" (Osborne, et al., 2003, p. 712). Duschl and colleagues therefore laid out a foundation for understanding this knowledge through their identification of NOS components. They then built upon this foundation in order to construe NOS more broadly in relation to the development of scientific knowledge.

NOS as a set of guiding principles. Most other researchers do not describe NOS as explicitly as Lederman and colleagues, Kimball, and Duschl and colleagues. However, their definitions also warrant consideration when describing current conceptualizations of NOS in this field. The descriptions addressed here present NOS not as sets of components, but instead treat NOS as guided by a set of broader principles that shape scientific practice.

The top-down approach: comprehensive principles of NOS and their underlying components. Driver, Leach, Millar, and Scott (1996) described students' conceptions of NOS as a series of three strands of understanding: (1) the purpose of scientific work; (2) the nature and status of scientific knowledge; and (3) science as a social enterprise. These authors then delineated their criteria for students' understanding of NOS in relation to each strand.

These descriptions exhibit substantial overlap with the conceptions put forth by Lederman and colleagues and, to some extent, those proposed by Duschl and colleagues, but are less closely tied to Kimball's views. In their description of the first and second strands calling for an understanding of the purpose of scientific work and the nature and status of scientific knowledge, Driver et al. (1996) asserted that the natural sciences explore the natural world and rely on observations and data to answer questions related to these phenomena. This clearly echoes the belief in the empirical nature of scientific inquiry described by Lederman and colleagues. Also like Lederman, Driver et al. placed value on understanding the role of theories and laws in the scientific enterprise. The authors further acknowledged that scientific claims are subject to change due to their conjectural nature, linking this strand to Lederman and colleagues', Duschl and colleagues', and Kimball's focus on the tentative nature of scientific knowledge.

The third and final strand, which claimed that science is a social enterprise, clearly echoes Duschl and colleagues' focus on the idea that science is the product of cooperation and collaboration. Although Driver and colleagues' emphasis on the social aspects of science may initially appear to align with Lederman and colleagues' belief in the sociocultural influences on science, closer evaluation of these statements reveals that they are actually concerned with completely different aspects of social settings. Driver et al. (1996) specifically stated that, “Scientific knowledge is the product of a *community*, not of an individual” (p. 44, italics in original). The authors therefore focused on the communal, distributed nature of the construction of scientific knowledge, specifically the means by which scientific knowledge is subject to review by others in the field, while Lederman and colleagues were primarily concerned with the ways in which certain sociocultural elements, such as politics and religion, influence the activities and focus of scientific work.

Like Driver et al. (1996), Southerland, Gess-Newsome, and Johnston (2003) conceptualized NOS broadly with three major components and then described each of these components in greater detail. In thinking about their studies of scientists’ portrayal of science in the college courses that they taught, the authors’ conception of NOS centered on three organizing elements: (1) science products; (2) science processes; and (3) science as a way of knowing about the world. Further descriptions of these aspects reveal both areas of overlap with and divergence from other definitions of NOS. The authors stated that science products primarily include concepts, facts, and theories of science. Furthermore, they acknowledged that scientific disciplines inform one another and that science can provide students with a way of viewing and interacting with the world. With regard to science processes, the authors emphasized the means by which the tools of scientific inquiry (for instance, observation and measurement) can be used in generating scientific knowledge. They went on to clarify that the roles of these inquiry tools should be considered in relation to problem solving, as problem solving is the primary process by which the development of scientific knowledge occurs. Finally, Southerland et al. (2003) explained that “science as a way of knowing was understood to capture the epistemological assumptions that underlie scientific knowledge and its generation” (p. 671). These assumptions were stated to include the empirical, tentative, and socially-situated nature of scientific knowledge and its development.

While these researchers’ assertions are not directly stated in other definitions of NOS, one can see that the more general principles proposed underlie many of the aspects of NOS described in other science education literature. For instance, the science processes and their role in the development of scientific knowledge as described by Southerland et al. (2003) align nicely with Duschl and colleagues’ NOS framework. Furthermore, parallels can be seen between Southerland’s description of science as a way of knowing and the purpose of scientific work and the nature and status of scientific knowledge proposed by Driver et al. (1996). Connections between Duschl and colleagues’ acknowledgement of the role of interdisciplinary collaboration and Southerland and colleagues’ claims about the integrated nature of science disciplines are also evident.

Although overlap exists between the work of Southerland et al. and other researchers, portions of these authors’ conceptualization of NOS are unique. Perhaps the most notable difference is that the authors’ assertions that an understanding of science may help individuals view and interact with the world differently are not addressed in other conceptions of NOS. The conception of NOS proposed by Southerland et al. is not, however, comprehensive. Conspicuously absent from their description is the idea of the tentative nature of scientific knowledge, which is present in all other conceptions described here. Some additional facets of NOS identified by other authors but overlooked here are the sociocultural influences on scientific practices, the lack of a universal scientific method, and the theory- and value-laden nature of scientific knowledge.

In comparison to researchers addressed previously, who focused primarily on the assortment of components that they believed constituted NOS, Driver and colleagues and Southerland and colleagues employed a more top-down approach. These authors developed frameworks that were more domain-general than those of other researchers by describing a few guiding principles of NOS and the underlying subcomponents of each. Consequently, these frameworks may be considered somewhat flexible in their application to a wider range of scientific practices, but also more subject to interpretation by both science researchers and educators. The degree to which these authors' frameworks could be incorrectly or inadequately interpreted may prove problematic, however. Individuals may treat the guiding principles included in each framework superficially, rather than considering the roles of the underlying components in any depth.

The generalization approach: Specific components of NOS and their universality. Like Duschl and colleagues, some other science education researchers have attempted to bridge existing gaps in NOS definitions by turning to sociology and philosophy of science. Some of these researchers have gone beyond Duschl's work, which focused on soliciting feedback from sociologists and philosophers of science, by actually consulting studies in these fields that were aimed at describing scientific research practices. The scope of this work has been rather limited, however, as these researchers did not attempt to lay out an entire NOS framework. Instead, these authors focused on particular aspects of scientific practice that they believed were relevant to NOS but that point to more universal aspects of activities within the field. Two research programs, specifically the work of Rudolph and Stewart (1998) and Ford (2008a; 2008b), explicitly address particular science practices and then link them to more generalized aspects of the enterprise of science.

Rudolph and Stewart (1998) worked within the context of evolution education, investigating why students may struggle with this topic. The authors traced changes in philosophers' views of science and stressed that the privilege historically placed on experimentation in certain sciences, particularly physics, has impeded students' ability to reason about research in evolutionary biology. Rudolph and Stewart went on to state that the focus of more recent work in the philosophy and sociology of science has shifted "toward viewing the various disciplines that comprise science as a set of distinct local practices rather than as parts of a unified system" (p. 1076) and has attempted to describe scientific practice and its underlying reasoning mechanisms as they occur in different disciplines more naturalistically. The authors argued that a focus on the ways in which the natural world is modeled in various scientific disciplines would be advantageous, as students would come to appreciate the ways in which models are used in exploration of, explanation of, and theory building about the natural world.

In related work, Stewart and Rudolph (2001) stressed the importance of using, generating, and revising models when working with both conceptual and empirical problems in order to comprehend the practices of science more effectively. In both studies the authors explained how these types of modeling activities may better equip students to reason about evolutionary biology, but as they further suggested, this may also be useful for other science disciplines. When considering other science education definitions of NOS, however, the concept of modeling is conspicuously absent. While some researchers may view Stewart and Rudolph's emphasis on modeling as a subset of scientific methods (e.g., Lederman and colleagues; Driver and colleagues), the ideas put forth by these authors suggest that the development, testing, and refinement of models is in fact the primary goal of scientific practice, and that other "methods" are selected in service of this objective.

Rather than lay out a full NOS framework, Ford (2008a; 2008b) similarly addressed particular aspects of scientific practice, specifically the processes of construction and critique of claims in scientific research, and their broader relation to NOS. He drew upon the ways in which sociological, philosophical, and historical studies of science "account for, or explain 'performance,' whether it be of individual scientists or of the scientific endeavor overall" (Ford, 2008a, p. 152). Ford posited that students need to understand how scientists go about developing claims about nature and how, through their interactions with one another (e.g., through peer review), the critiques and resulting revisions of these claims allow them to be held accountable and ultimately to gain authoritative status. Like the work of others in science education discussed previously, Ford stressed that the construction and critique of claims are inherently social in nature, as the interactions among scientists are crucial for their occurrence. Ford further suggested that these activities are central to scientific practice and therefore deserve greater attention when developing an understanding of NOS, particularly since they occur across disciplines.

Review of the science education literature addressing NOS clearly reveals areas of overlap and divergence in the ways in which it is conceptualized. Some definitions are more focused on identifying individual components of NOS, while others attempt to identify broader, more universal principles underlying NOS. Other science education research that is not directly aimed at conceptualizing NOS also sheds light upon aspects of scientific practice that are overlooked in many current definitions. Like the work of Stewart and Rudolph, as well as that of Ford, these reports typically focus on the importance of particular scientific practices, but are still useful when reconceptualizing NOS on a broader scale.

Insights from other science education research. Other work in science education that does not directly address or define NOS identifies and expands upon particular scientific practices considered important for an understanding of the enterprise of science and, consequently, science education. Similar to the work of Stewart and Rudolph, for instance, Lehrer, Schauble, and Petrosino (2001), drawing upon insights gained from sociological studies of science, emphasized the idea that modeling is the fundamental activity of science, as models function as scientific arguments. They further reiterated Rudolph and Stewart’s (1998) claim regarding the prevailing emphasis placed on experimentation in science education, stating that it “is an insufficient target for sustaining either effective instruction or an adequate account of the development of scientific reasoning” (Lehrer, Schauble, & Petrosino, 2001, p. 275). The work of Windschitl, Thompson, and Braaten (2008) similarly emphasized the need for the importance of modeling to be communicated to students and proposed a framework by which students could come to understand how models are created and revised and ultimately function as scientific arguments.

Related work conducted by Duschl and Osborne (2002) was *not* explicitly focused on defining NOS, yet is still useful when thinking about its reconceptualization. In this work, the authors primarily emphasized the role of argumentation in science. Drawing upon sociological studies of science, Duschl and Osborne proposed that argumentation is a core activity in science that cultivates the development of connections between data and theory. Modeling (as described by Lehrer and colleagues and Windschitl and colleagues) and argumentation (as described by Duschl and Osborne), as fundamental activities of science, are distinct from the aspects of NOS described in the science education literature (e.g., the science processes described by Southerland et al., 2003), and are not addressed explicitly in most NOS definitions. These crucial concepts of modeling and argumentation, as well as the roles of other processes of science (e.g., hypothesis generation, experimentation, and data analysis) in model and argument development, may therefore be inadequately addressed or overlooked entirely in science classes.

Kelly, Carlsen, and Cunningham (1993) advocated the examination of sociological studies of science as a means to describe the sociocultural context of science research in greater depth than is reflected in existing NOS research. The authors suggested several implications of sociological studies of science for science education, including (but not limited to) the need to emphasize the social conditions within which scientific work occurs and the importance of understanding the process of science (i.e., "the process from which data are gathered, organized, interpolated, and interpreted," p. 216) in addition to science content. Cunningham and Helms (1998) made similarly expansive claims about the idea that sociological studies of science describe work in science disciplines more realistically than what is typically portrayed "in most science textbooks or classrooms as well as the impressions held by much of the general public" (p. 484) and should therefore be considered in science education reform efforts. Having distinguished between *microsociological* (at the individual level and within the science community) and *macrosociological* (referring to the interactions between science and society) studies, the authors made recommendations regarding how issues raised by these studies might be addressed in classroom practice based on two teacher case studies, albeit focusing primarily on microsociological issues. One teacher engaged her students in an extended, open-ended laboratory experience in which they developed and investigated their own research questions, engaged in collaborative interactions with peers, presented their findings to the class, and, in some cases, conducted extended follow-up investigations of new research questions that arose. The other teacher described in Cunningham and Helms' study asked students to read and critique scientific articles and then apply their critiquing skills to their own classroom investigations. Based on their findings, the authors suggested that "by engaging students in practices that mimic those of real science and asking students to reflect upon science, the activities communicate messages about networking, peer review, and skepticism" (p. 491).

While studies such as these are indeed useful when considering the ways in which sociological studies of science might inform science education research, they currently remain essentially detached from efforts aimed at defining NOS. These types of studies, however, can be used to inform the development of a more authentic conception of NOS. In spite of the wide variety of aspects of scientific practice described throughout science education research literature, both in definitions of NOS and other work, some less visible aspects of scientific practice revealed through studies in the sociology and philosophy of science still remain largely unaddressed. Along with insights gained from existing science education research, studies in these fields can be used to augment and refine existing definitions of NOS in order to develop a more authentic, domain-general conceptualization. I therefore turn to a review of the sociology and philosophy of science literature, identifying the ways in which it is useful when reconceptualizing NOS.

Sociology and Philosophy of Science Perspectives

Although not aimed at explicitly defining NOS, particularly in relation to science education, sociological and philosophical studies of science provide insight into practices of professional science that may be useful when rethinking this concept, as these types of studies are designed to portray the activities of scientific practice more authentically. Aspects of scientific practice that are largely invisible to *both* science insiders and outsiders are highlighted in sociological and philosophical studies of science, particularly the ways in which arguments are constructed, substantiated, challenged, and (potentially) revised. In reading this literature, aspects of NOS that are generally overlooked or underdeveloped in science education, particularly science education researchers' current definitions of NOS, become evident.

Scientific practice: A broader picture. Perhaps one of the most useful ways of thinking about the activities of scientific practice as a whole is though the distinction between *science in the making* (or *science in action*) and *ready-made science* proposed by Latour (1987). Latour distinguished *science in the making* as the messy, ongoing activities of theory-building science research exploring unfamiliar or contested phenomena, whereas *ready-made science* deals primarily with widely-accepted ideas, facts, or theories through “the orderly pattern of scientific method and rationality” (p. 15). As described elsewhere in this text, the generation and revision of models is the key activity for science researchers and constitutes much of their work in science in the making. Unfortunately, much of school science, with its prevailing focus upon facts as its primary content, more closely resembles ready-made science than science in the making. Students may therefore be deprived of opportunities to learn about the complex means by which scientific knowledge is produced, revised, and refined, thereby impeding the development of their understanding of NOS. Attention to model building and model-based reasoning in school science may provide students with avenues to explore science in the making and gain a better understanding of authentic scientific practice.

Science as a community of practice. Several of the science education studies previously discussed addressed the social aspects of scientific practice; nonetheless, these researchers have generally failed to characterize the enterprise of science as what Lave and Wenger (1991) called a *community of practice*. According to these authors, “A community of practice is a set of relations among persons, activity, and world, over time and in relation with other tangential and overlapping communities of practice” (p. 98). When considered as a community of practice, particularly in relation to the sociology and philosophy of science literature, certain aspects of scientific practice that are inadequately addressed in existing NOS definitions surface.

One overarching aspect distinguishing the scientific community of practice from other such communities is the role of language as employed by researchers within science disciplines. Lemke (1990) wrote specifically about this unique role of language, detailing the ways in which particular semantic patterns are typically valued when reasoning scientifically and constructing scientific arguments. He went on to state:

> The mastery of a specialized subject like science is in large part mastery of its specialized ways of using language. What makes the language of science distinctive is primarily, but not exclusively, its *semantics*: the specific relationships of scientific meanings to one another, and how those relationships are assembled into thematic patterns. (p. 21, italics in original)

Lemke went on to state that the communal semantic patterns that dominate both spoken and written language in science are one means by which individuals may be included in or excluded from the scientific community of practice, as those who are unfamiliar with these patterns may have difficulty interpreting written or spoken science material.

Yet another feature of this community of practice is the ways in which knowledge within science, even within different disciplines, is not maintained solely in the mind of one individual, but is actually distributed across individuals in space and time. Hutchins' (1996) description of distributed cognition, albeit in relation to ship navigation, provides an interesting lens with which scientific practice can be considered, as scientists within and across disciplines collaborate (as well as compete with one another) in order to produce arguments systematically. Therefore, contrary to the typical received view of science in which individual scientists work in isolation to produce and interpret data, science researchers more often act in networks, drawing upon the expertise of others to inform their thinking. The nature of these collaborations and competitions subjects scientific knowledge to ongoing critique by researchers' peers, often requiring scientists to rethink or refine their arguments. Knowledge is therefore socially constructed within the scientific community of practice rather than constructed by individual researchers.

Giere (2002) further expanded on Hutchins' work, branching into scientific practices through observations of scientists' interactions within a laboratory. Drawing upon Hutchins' proposal that distributed cognition extends beyond humans to include the physical tools used when carrying out a task, he observed the researchers' interactions both with one another and with instruments that they used to conduct their investigations. Giere consequently concluded that "to understand the workings of the big cognitive system [of a research laboratory] one has to consider the human-machine interactions as well as the human-human interactions" (p. 292). He further explained that, using the lens of distributed cognition, he came to see visual representations as part of the cognitive system within which scientists operate. Giere also considered models with respect to distributed cognition and stated that:

> Most models in science, even in classical mechanics, are too complex to be fully realized as mental models...Rather, the details of these models are *reconstructed* as external representations when needed. These reconstructions typically take the form of equations or diagrams. (pp. 293-294, italics in original)

This view of modeling in science thus renders evident the interplay that exists between the scientists' reasoning and the physical representation of aspects of mental models on which they base this reasoning.

Latour's (1999) work, which described the creation and dissemination of inscriptions among researchers for use in various settings, illustrated yet another way in which cognition is not maintained solely in the head of an individual. His study of researchers in the Amazon instead highlighted that cognition is to some extent contained within the tools used and artifacts generated during scientific research.

Pickering (1993) metaphorically described these interactions between scientists and the material aspects of their work as the *mangle of practice*. Pickering stated that, "I take the mangle to refer . . . to an overall image of practice . . . to the worldview . . . that sees science as . . . an evolving field of human and material agencies reciprocally engaged in the play of resistance and accommodation" (p. 567). *Resistance*, as described by the author, refers to the obstacles encountered by scientists as they conduct their work (including those that arise when natural phenomena or models of such phenomena perform differently than anticipated), while *accommodation* was described as adjustments made by scientists in response to resistances that arise. Using research in particle physics as an illustrative case, Pickering discussed the ways in which the *dialectic of resistance and accommodation* allowed researchers to make progress toward their goals, perhaps using different approaches or strategies than initially intended.

Taken broadly, the concept of the mangle of practice describes resistances posed not only by products generated by scientists during their own research, but also knowledge and artifacts produced by prior, ongoing, and future research conducted by other scientists. This ongoing, historical dialectic continually shapes the development and reproduction of scientific knowledge. While several existing definitions of NOS attempt to account for the susceptibility of scientific knowledge to change by noting its tentative character, Pickering's dialectic of resistance and accommodation and the processes underlying this dialectic provides a lens for deeper conceptualization of how ongoing changes occur in the development of scientific knowledge.

The discursive and structural features of the knowledge produced in science disciplines, as described by Lemke, Hutchins, Giere, Latour, and Pickering, are important for an understanding of the scientific community of practice, the ways in which this community functions, and, therefore, the ways in which scientific knowledge develops. Although several of the definitions of NOS previously described make reference to the social aspects of scientific practice, these conceptions fail to address these particular features adequately. Yet another overarching feature of science that is *not* stressed in current definitions of NOS is how these aspects of scientific practice (i.e., discourse and the distributed nature of scientific knowledge), as well as modeling and representation (to be discussed further) are all interrelated to contribute to the unique community of practice that is science.

Methodologies of science. As one becomes familiar with the expansive community of scientific practice, it becomes increasingly evident that sub-communities associated with different disciplines also exist. The distinction between approaches among (and even within) disciplines was delineated by Bauer (1992) when describing the *myth of the scientific method.* Bauer attempted to dispel the received view of the strict, step-by-step approach toward scientific discovery by highlighting differences in approaches within science and the ways in which these approaches may inform various research agendas. Instead, the author proposed that more accurate characterizations of scientific practice reflect the cooperative aspects of scientific practice. Specifically, he first described Polanyi's metaphor, which suggested that science more closely resembles a jigsaw puzzle, in which researchers collaborate to achieve an over-arching goal. Bauer then refined this metaphor by focusing on the specific activities in which researchers are engaged as they generate scientific knowledge. He described these activities as acting as a filter through which “scientific knowledge . . . is gleaned from a mess of all sorts of suggestions, claims, and beliefs by progressive refining as errors and inadequacies are filtered out” (pp. 44-46) by being subjected to different levels of scrutiny by other members of the scientific community.

Despite this lack of a universal scientific method, certain types of practices *are* evident across science disciplines. The importance of modeling and representation in science are discussed to some extent in the science education literature, primarily by researchers who have addressed concerns raised by sociologists and philosophers of science (see, for example, Lehrer, Schauble, & Petrosino, 2001; Rudolph & Stewart, 1998; and Windschitl, Thompson, and Braaten, 2008). In his description of scientific reasoning, Giere (1997) discussed the means by which scientists attempt to develop models that align closely with phenomena in the natural world, maintain a level of predictive value, and against which data collected from the real world can be compared. The author further stressed the role of modeling in science by describing three different types of models that might be employed: (1) scale models, or physical models built to reconstruct objects either smaller or larger in size than as they occur in nature; (2) analog models based on structures that correspond to those occurring naturally; and (3) theoretical models, which are descriptions of natural phenomena rather than physical constructions and therefore do “not exist anywhere except in scientists’ minds or as the abstract subject of verbal descriptions that scientists may write down” (p. 24).

In related work, Nersessian (2002) explored cognition in the sciences, specifically in relation to modeling and changes in representational practices. Like Giere, the author identified several types of modeling processes that typically occur in science (analogical, visual, and simulative), which Nersessian considered as:

> highly effective means of making evident and abstracting constraints of existing representational systems and, in light of constraints provided by the target problem, effective means of integrating constraints from multiple representations such that novel representational structures result. (p. 145)

In her later work with Osbeck describing activities centered on model-based representation in two biomedical engineering laboratories, Nersessian (Osbeck & Nersessian, 2006) again made distinctions regarding model types. In this description, however, the authors distinguished between qualitative, quantitative, and simulative models. Furthermore, Osbeck and Nersessian tied modeling to Hutchins' conception of distributed cognition, stating that the models themselves acted as parts of the cognitive system within which the science researchers operated.

Latour's (1999) previously-discussed work that centered on inscriptions and the ways in which they are used by researchers further illuminates model use in science. Although specific types of models are not described as explicitly as in the work of Giere or Nersessian and Osbeck, his description of the roles of reduction and amplification in transforming the natural world into representations illustrates the core activities involved in modeling. The process of reduction, by which particulars of a natural system are systematically removed in favor of preserving the features most pertinent to its functioning, parallels the development (either physically or theoretically) of models aimed at representing aspects of the natural world. As the natural system of interest undergoes this reduction, the applicability of the model to other systems becomes more generalizable through the process of amplification. In becoming more universal, the model can be used to reason about a wider range of phenomena in the natural world.

Taken together, the work of Giere, Nersessian and Osbeck, and Latour points to a variety of ways that modeling serves as the basis for scientific reasoning and problem solving. Although some of the science education researchers previously identified have taken these ideas about modeling into account, having viewed them as relevant to and important for science education, the majority of NOS researchers have downplayed (if not completely overlooked) their value and the crucial role that they play in scientific reasoning and the development of scientific knowledge. These NOS researchers may regard modeling merely as one of an assortment of methods employed in (or activities that take place during) scientific research instead of recognizing the central role of modeling as stressed by philosophers and sociologists of science. Clearly, despite attempts by some NOS researchers to include aspects of scientific practice highlighted by sociological and philosophical studies of science, most of these attempts have been superficial, at best. These features of practice need to be foregrounded more explicitly in order to generate a more authentic, domain-general depiction of scientific practice.

Reconceptualizing the Nature of Science

Given the apparent lack of consensus on the definition of NOS in the science education literature previously identified, as well as the aspects of NOS that are highlighted in sociological and philosophical studies of science, I propose that a new NOS framework may be generated by drawing upon the various definitions presented in the science education research literature and revising and reorganizing them based on insights gained from the fields of sociology and philosophy of science. This framework is designed to provide a more authentic, generalizable depiction of scientific practice than existing NOS descriptions, asserting that the nature of science becomes most evident through consideration of science as community of practice characterized and/or shaped by three primary factors: (1) social structures; (2) the products and goals of science; and (3) the fact that science is a human-constructed endeavor. An overview summarizing this framework is provided (Figure 1), and each of these three factors is subsequently described. Although the factors are listed as individual components, it is the ways in which they relate to one another and converge to influence the scientific community of practice that truly constitute NOS. Therefore, these factors should not be considered merely as independent entities, but as a set that cannot be deconstructed without compromising NOS understanding.

Nature of Science:

Science as a Community of Practice

Social Structures

Construction and Critique of Claims

- *Scientific argument*
- *Discursive norms*

Intellectual Interdependence

- *Intra- and interdisciplinary exchange*

Products and Goals of Science

Variability of Methodology

Scientific Knowledge

- *Generative*
- *Co-constructed*
- *Tentative/subject to change*

Modeling and Inscribing

- *Types of models*

Science as a Human-constructed Endeavor

Historical & Contemporary Context

- *Beliefs and values*
- *Creativity*

Figure 1. Reconceptualized NOS framework.

Social structures. Particular social structures dominate much of scientific practice and distinguish it from other communities of practice. Specifically, these include the construction and critique of claims and the intellectual interdependence that exists in the sciences. Although these social structures may also be present in other communities of practice, the unique form that they take within science is important. Prior NOS researchers have attempted to account for some of the social features inherent to NOS, however they have failed to address these two important components adequately, nor have they considered them in relation to the scientific community of practice.

Construction and critique of claims. Insight into characteristic communication practices among scientists is important for conceiving of science as a community of practice, as the means by which information is conveyed in science is grounded in the construction and critique of claims. Individuals therefore need to understand the ways in which coherent scientific arguments, interpretable both within and across science disciplines, are constructed. Although the evidence provided in support of scientific arguments varies greatly among disciplines, and consequently the *forms* that these arguments take differ, they are generally designed to convince others of the validity of scientists' reasoning. In coming to understand how scientists develop an argument, individuals should learn to frame evidence in support of or refuting their conjectures, communicate these ideas to others, and engage in discussions about their knowledge and thinking (as well as the knowledge and thinking of others). Without such an understanding, one cannot fully comprehend the ways in which scientific claims and arguments are constructed, critiqued, refined, and ultimately made public, thereby preventing individuals from being able to think critically about issues that they may encounter in everyday life as consumers of science-related information.

Once an understanding of the construction of scientific arguments has been established, it may be useful for the discursive norms of written and spoken language in science to be explored more fully. Lemke's (1990) characterization of the language and semantic patterns that permeate written and oral discourse in science suggests that an understanding of scientific practice necessitates familiarity with the role of language in science. In order to comprehend these discursive norms, individuals should gain an understanding of the overall language patterns that are employed in communicating scientific arguments, including the "various rhetorical structure patterns . . . [that are] characteristic of science as a specialized discipline" (Lemke, 1990, p. 123). As Lemke pointed out, familiarity with the ways in which scientific language dehumanizes the enterprise of science (e.g., through use of passive voice) is important, as these language conventions may lead to science being viewed as inaccessible and/or authoritative. Without such understanding, science may also be viewed "as a simple description of the way the world is, rather than as a human social activity, an effort to make sense of the world" (pp. 130-131). This, in turn, may preclude deep understanding of science as a community of practice. Furthermore, acquiring knowledge of technical aspects of spoken and written scientific discourse (e.g., grammatical norms) and the reasoning behind these conventions may aid in the development of an individual's understanding of the construction of scientific arguments, as they effectively restrict the ways in which acceptable arguments can be stated. This knowledge may prove useful to individuals when confronted with scientific material, particularly written texts, as they could think more critically about the ways in which scientific arguments are framed and the implications of this framing for an argument's validity.

Intellectual interdependence. In order to develop appropriate conceptions of NOS, it is important that individuals come to understand the intellectual interdependence that exists in the sciences. Developing awareness of the intradisciplinary and interdisciplinary exchanges that take place among scientists is particularly critical for understanding the uniqueness of the scientific community of practice. Rather than viewing science as occurring solely in the mind of a single individual, one must be aware of the interactions that occur among researchers, both within and between science disciplines, as scientific discovery rarely occurs in isolation. For example, advances in the field of pharmacology have resulted from cross-talk between the life sciences and physical sciences. Without collaboration between scientists in these disciplines, with each contributing their own perspective and expertise for moving toward a common goal, progress in pharmacology likely would not have been possible. Awareness of these types of interconnections among and between different fields of science may also help individuals comprehend the ways in which seemingly unrelated pieces of scientific knowledge fit together for a broader understanding of the natural world. Similar forms of intellectual exchange may also occur more locally, as individuals working within a specific research setting may work on different individual projects that contribute to further an overarching research goal (e.g., graduate students and post-doctoral fellows conducting research on separate projects that converge to advance a principal investigator's broader research agenda).

It is also important to remain cognizant that modern research practices have built upon previously-developed thinking and technologies, thereby requiring that researchers not only directly interact with each other, but also with individuals who are not immediately available to them. This may involve consultation of existing literature to draw upon another perspective on or related to a phenomenon, or employing or adapting a specific research protocol or technology to investigate a phenomenon, possibly in ways different from the creator's original intent. Although the creators of such literature or technology may not be available for consultation for various reasons (e.g., they are no longer living, or are simply unable to be contacted), practicing scientists still draw upon their expertise while conducting their ongoing research. This, therefore, constitutes another form of intellectual exchange within the scientific community of practice.

Products and goals of science. While research in any field is goal-oriented, the particular products generated through and goals of scientific research are distinctive. The variety of methodologies employed by scientists as they do their work, the types of knowledge produced in science, and the means by which scientists attempt to model the natural world so that it may be better understood are characteristic of the scientific community of practice. Some subcomponents of these features may be visible in other fields, but it is when they are taken together that the truly unique nature of science emerges.

Variability of methodology. The canonical view of the scientific method that permeates much of school science implies that research in science takes place through a series of discreet, ordered steps through which all scientists progress and from which they never waver as they conduct experiments to test their hypotheses. The inaccuracy of this model of scientific work is described in detail by Bauer (1992) when describing the *myth of the scientific method*. In reality, the work of science is much messier than the scientific method implies. Not only do scientists *not* adhere to such a rigid set of steps as they conduct research (as they constantly refine their questions, conjectures and methods throughout their work), not all scientists employ the same approaches to investigate their questions. The scientific method generally maintains that scientists conduct experiments in order to answer their research questions. This is not always the case, however. Take, for example, the work of evolutionary biologists. Their work is based largely on comparative study rather than experiments. This does not make their work any less valid, yet it is completely overlooked by the framework of the scientific method. An understanding of this methodological variation precludes one from falsely believing in the existence of one universal Scientific Method, which enhances an understanding of the activities within the scientific community of practice and, consequently, the nature of science.

The nature of scientific knowledge. Three aspects of scientific knowledge are important for appreciating how it is built and perceived by members of the scientific community of practice. Specifically, these aspects include the ideas that scientific knowledge is (1) generative, (2) co-constructed, and (3) tentative, and therefore subject to change. The first of these, the generative nature of scientific knowledge, refers to the idea that scientific research is aimed at producing new knowledge, as well as refining existing knowledge. As this occurs, new avenues for exploration emerge. School science, in contrast, all too often portrays scientific research as a process of verification, as students conduct scripted experiments designed to elicit particular expected outcomes in order to confirm a pre-determined hypothesis. In doing so, school science conceals the nature of scientific discoveries.

The idea that scientific knowledge is co-constructed ties closely to the intellectual exchange that takes place in science as discussed previously. This co-construction occurs as a result of collaborations among scientists working together to generate new knowledge. The tentative nature of scientific knowledge, which allows it to be open to change, is similarly tied to social structures of the scientific community of practice. Discursive practices associated with the construction, critique, and revision of claims leave room for change. Furthermore, as researchers encounter resistance to their claims and make accommodations (as described by Pickering, 1993) to cope with these resistances, their arguments may shift in both form and content. Such changes to scientific knowledge are not restricted to short-term time scales, as even long-held beliefs about certain phenomena are subject to change as new knowledge emerges.

Modeling and inscribing. Although modeling and inscription practices in general are not necessarily confined solely to the scientific community of practice (e.g., architects construct scale models of buildings during their planning), certain aspects of these practices in science disciplines are unique to the field. Only scientific models and inscriptions are intended to represent aspects of the natural world, and while the process of reduction may appear to somewhat simplify them, the corresponding amplification described by Latour (1999) that occurs subsequently allows the model to potentially be applied more broadly. His description of the roles of reduction and amplification in transforming the natural world into representations illustrates the core activities involved in modeling and inscription. The process of reduction, by which particulars of a natural system are systematically removed in favor of preserving the features most pertinent to its functioning, parallels the development (either physically or theoretically) of models and inscriptions aimed at representing aspects of the natural world. As the natural system of interest undergoes this reduction, the applicability of the model or inscription to other systems becomes more generalizable through the process of amplification. In becoming more universal, the model or inscription can be used to reason about a wider range of phenomena in the natural world.

There are a range of methods for generating these models, as well as types of models used, many of which can be specific to particular subdisciplines within science. For instance, those researchers who do employ experimental techniques are striving to model some aspect of the world through their actual experiment, other models may take the form of mathematical equations, and still others may be computer-based or other forms of simulation. This, in turn, reiterates the idea that scientific research cannot be characterized through a single scientific method, as different forms of research rely on and generate different forms of models. Thus, an understanding of the importance and meaning of modeling in science, as well as the types of models employed and generated throughout scientific research, are necessary for a sophisticated understanding of NOS.

Science as a human-constructed endeavor. Despite the pervasive belief in the objectivity of science and the knowledge it produces (Bauer, 1992), several factors influence the focus of scientific research, as well as the ways in which it is conducted. These factors can generally be categorized as the historical and contemporary context within which research takes place. Within this category, both societal influences and the influence of the individual conducting the research can be examined.

Historical and contemporary context. Above all, one must remember that scientific research is a human endeavor. For this reason, one must consider the fact that the beliefs and values maintained by society as a whole and the scientific community of practice influence the types of scientific research viewed as important and consequently pursued. As Kelly, Carlsen, & Cunningham (1993) pointed out, "Science is a product of the culture that produces it. Therefore, it is a mistake to assume that science can achieve conclusions independent of the larger social context in which it works" (p. 213). Both historical and contemporary social issues such as politics, finance, and military-related concerns (among others) influence not only the ways in which scientific research is conducted, but also funded. It is precisely for this reason that one must remain cognizant of the context in which scientific research is conducted.

In addition to the influence of the beliefs and values of the society in which a researcher works exerts on his or her work, a researcher's own beliefs and values may also influence the work. Scientific research and its resulting knowledge are therefore largely perceived as *value-laden*. Furthermore, this knowledge may also be viewed as *theory-laden*, as individuals' personal theories about the world and how it works also drive their research. Bauer (1992) described the theory-laden nature of scientific knowledge by stating that "there is no such thing as a definite piece of indisputable knowledge about the world whose meaning is not in some way colored by preexisting belief about the world" (p. 65).

In addition to these influences on scientific practice, sheer creativity is also important. Science researchers' abilities to conceive of research questions, determine strategies for answering their questions, analyze the information collected in relation to their questions, and craft convincing arguments about some aspect of nature requires a great deal of ingenuity. Therefore, while creativity is not a characteristic confined to the scientific community of practice, it is certainly vital to its existence.

Discussion of the reconceptualized NOS framework. The reconceptualized NOS framework presented here draws upon existing science education researchers' definitions of this concept, as well as insights into practices of science highlighted in both science education research that did not explicitly define NOS and in sociological and philosophical studies of scientific practice. The literature reviewed that did *not* directly address NOS helped augment existing definitions, as well as reframe several of the components of these definitions as proposed by NOS researchers. By considering each of these sets of literature, I aimed to develop a conceptualization of NOS that is both more authentic and domain-general than existing definitions.

With regard to authenticity, I propose that, by drawing upon sociological and philosophical science studies (as well as the science education literature not directly addressing NOS), my framework is more reflective of scientific research activity. For example, although some NOS researchers' current definitions address some social aspects of scientific practice (e.g., Driver and colleagues; Duschl and colleagues), ideas about discursive norms in science are largely absent. While Ford (2008a) generally addressed the means by which claims are constructed and critiqued in science, he failed to describe the role of language and semantic patterns in the depth illustrated by Lemke (1990). Furthermore, despite some NOS researchers' attention to the distributed nature of cognition in science (e.g., Driver and colleagues' emphasis on the socially-constructed nature of scientific knowledge), the role of inscription devices and their products are not addressed. Therefore, although some NOS researchers have made efforts to address issues related to my reconceptualized framework, this new perspective provides greater insight into the actual scientific practices underlying these broader themes.

While my framework aims to describe scientific practices more authentically, it is also designed to highlight and prioritize practices that are employed across disciplines and is, consequently, more domain-general than current conceptions of NOS. Modeling, for example, is valued greatly as the primary activity of science by sociologists and philosophers of science (e.g., Giere; Nersessian and colleagues), as well as several science education researchers who are not focused on defining NOS. In spite of these perspectives, modeling has received little attention in current NOS definitions. With the exception of Stewart and Rudolph (2001), in fact, none of the NOS researchers included here addressed modeling. Although different disciplines may rely on different types of models, modeling overall is employed across all disciplines, and is therefore domain-general in nature. Additionally, although discussed previously as being close to actual scientific practice, the discursive norms associated with science can also be considered domain-general. Certainly domain-specific vocabulary exists within disciplines, but the collective role of language in the construction of scientific arguments is fairly universal. By attending to each of these authentic yet domain-general aspects of science, I believe that one can acquire a deeper understanding of how the scientific community of practice functions.

Perhaps most importantly, however, this framework is designed to function as a cohesive set of interrelated principles that are critical to understanding science as a community of practice. Therefore, all of the components in the framework *together* constitute NOS and should not be considered independent entities. Some existing literature aimed at defining NOS describes its components in relative isolation, and even those definitions that take a more top-down approach (e.g., Southerland and colleagues) do not explicitly draw connections between the principles identified as guiding NOS. This reconceptualized framework, however, acknowledges the inextricable relationships that exist between its components. For example, the means by which scientific knowledge is co-constructed is tightly tied to the underlying social structures (particularly distributed cognition) of the scientific community of practice and is simultaneously shaped by the beliefs and values of those individuals responsible for its co-construction. It is therefore impossible to consider the co-construction of scientific knowledge without also attending to these other factors. This unique interplay that exists between elements of the scientific community of practice is what constitutes NOS. Without an understanding of these relationships, deep understanding of NOS cannot be achieved.

The reconceptualized NOS framework, teacher understanding, and classroom instruction. As noted previously, there is a call within the science education community for students to develop an understanding of NOS, regardless of whether or not they pursue careers in the sciences, in order to function as informed members of society. Students' classroom teachers, then, are charged with the responsibility of guiding the development of this understanding. In order for teachers to be effective in communicating adequate conceptions of NOS to their students, they themselves must possess an understanding of NOS. This has widespread implications for both pre-service and in-service teacher education programs, as there is no guarantee that teachers will develop this understanding independently, as evidenced by the prior research reviewed by

Lederman (1992). It is therefore worthwhile to consider what types of experiences will help pre- and in-service teachers develop conceptions of NOS that align with the framework presented here.

In addition to exploring the types of activities that support the development of teachers' understanding of NOS, we must consider how teachers' adequate conceptions of NOS may be translated into their classroom instructional practices. This translation is necessary to ensure that students can be exposed to their teachers' understanding and increase the likelihood that they, too, will develop conceptions of NOS aligned with this reconceptualized framework. Therefore, further research into the ways in which teachers can communicate adequate conceptions of NOS is needed.

Research on the development of teachers' NOS conceptions in relation to my framework, as well as the connections between these conceptions and classroom instruction, will allow science education researchers to design and/or evaluate programs for both pre- and in-service teachers aimed at improving NOS education. Furthermore, this type of research focus may lead to the development of curricula that aid teachers in communicating ideas about NOS to their students. Advancements in both of these areas of research are necessary in order to help students achieve the understanding of NOS called for by the science education community.

Understanding the Nature of Science

In order for students to gain a deeper understanding of NOS, they should be exposed to elements of the relevant concepts throughout their K-12 education. This logically necessitates that teachers possess sophisticated understandings of NOS, as well as the ability to communicate these conceptions of NOS to their students effectively. In addition to his findings regarding students' understanding of NOS reported earlier, Lederman's (1992) review of NOS studies also identified shortcomings with respect to teachers' NOS understanding, thereby suggesting that there is no guarantee that teachers will develop adequate conception of NOS through their training or independently. For instance, according to some of the studies of pre- and in-service teachers reviewed by Lederman, teachers failed to conceive of scientific knowledge as tentative, emphasized the scientific method, and "believed that science was either a body of knowledge consisting of a collection of observations and explanations or of propositions that have been proven to be correct" (p. 344). Again, although these studies of teacher understanding of NOS employed different frameworks than the one described here, it is likely that teachers' conceptions would also be found to be insufficient with regard to my reconceptualized definition due to its expanded breadth of focus. We must therefore consider how teacher understanding of NOS might be improved and subsequently translated into instruction so that students can ultimately benefit from this knowledge. Specifically, it is worthwhile to consider what types of experiences will help pre- and in-service teachers develop conceptions of NOS that align with the framework presented here.

Developing NOS Understanding

Given Lave and Wenger's (1991) framework for situated learning through legitimate peripheral participation, it might be expected that participation in the enterprise of science would provide an individual with a deeper understanding of NOS. Individuals who participate in scientific research begin as newcomers, learn about the practices of science from more knowledgeable old-timers such as research professors and/or graduate students, and eventually transition to acting as old-timer participants as they become familiar with the norms and goals of the scientific community of practice. Therefore, it is possible that by actually participating in the practice of science, individuals may gain a deeper understanding of NOS. Students in K-12 settings rarely have opportunities to work directly with researchers; therefore, science teachers themselves must serve as the relative old-timers in the practices of science so that they can effectively mentor their students.

While it may not be practical for teachers to become as knowledgeable about the practices of science as those who participate in them professionally, some progression toward a more expert stance through participation in research may prove beneficial. For a variety of reasons, however, teachers may not participate directly in scientific research during their own education or preparation for teaching. This is in large part due to the coursework and training in which pre-service teachers enroll as undergraduates, as even future educators who major in science likely participate in courses and laboratories primarily aimed at memorization and verification of existing scientific knowledge. As noted by Kindfield and Singer-Gabella (2010), all too often “we find ourselves in an entrenched cycle in which teachers from elementary school through college teach science as it was taught to them – giving content-jammed lectures…and running labs that at best include contrived inquiry projects but more often than not follow a cookbook model” (p. 61). (This is in stark contrast to those individuals who pursue careers in scientific research and typically undergo extensive post-graduate training, during which they engage in scientific research as apprentices in order to become experts in the domain.)

The context in which teachers educate their students may also influence their thinking about NOS and the ways in which they represent NOS to their students. For instance, curricular materials convey certain images of NOS to both teachers and students, such as the idea of a universal scientific method. Furthermore, the disjointed ways in which science is typically taught (that is, in disconnected units of study such as a course/unit in biology followed by a course/unit in physics which in no way connects to the former) portrays science disciplines as completely separate from one another. These depictions do not align with my aforementioned framework. Consequently, teacher involvement in authentic scientific research activities through teacher training and/or professional development programs may be crucial to the development of their understanding of the nature of science, as is finding pathways for them to communicate such understanding to their students.

Related literature describing the processes of learning through intent participation (Rogoff et al., 2003) similarly suggests that individuals may learn through observation of and participation in cultural practices associated with a particular community. Therefore, individuals may gradually become inducted into the scientific community of practice as they progress from observers to practitioners of science. As the authors describe:

> [I]n intent participation, learners engage collaboratively with others in the social world. Hence, there is no boundary dividing them into sides. There is also no separation of learning into an isolated assembly phase, with exercises for the immature, out of the context of the intended activity. (p. 182)

While teachers themselves likely learned science through the assembly-line structure described in this work throughout their own schooling, participation in scientific research may afford them the opportunity to learn about NOS through intent participation. In keeping with this model, the more-knowledgeable individuals with whom they interact, such as research professors and/or graduate students, are in a position to provide expertise and guidance for teachers in relation to content and research methodologies throughout their research experience. Meanwhile, these more-expert individuals are also actively engaged in the ongoing research process, "often participating alongside learners—indeed, often learning themselves" (p. 187). These opportunities for drawing upon the knowledge base of others through collaboration around scientific research may serve as powerful tools for bolstering teachers' understanding of NOS.

Consideration of teachers' participation in science research using Goodwin's (1994) lens of professional vision similarly provides insight into the potential benefits of such activities. Goodwin asserts that professional vision "consists of socially organized ways of seeing and understanding events that are answerable to the distinctive interests of a particular social group" (p. 606). Given that science teachers' professional vision is likely centered primarily on teaching, one might assume that their vision is quite unlike that of research scientists. The distinct professional visions of teacher and scientist may lead to very different views of NOS, as they likely influence individuals' understanding of the practices of science research. It may therefore be argued that, in order for teachers to develop conceptualizations of NOS that more closely resemble that of science researchers, they should be exposed to the professional vision of these researchers. This may occur through hands-on participation in the scientific community of practice.

Given the perspectives provided by Lave and Wenger (1991), Rogoff et al (2003), and Goodwin (1994), I hypothesize that exposure to and participation in scientific research practices may be effective for the improvement of teachers' NOS understanding. I do not intend to suggest that simply working with any scientist in a laboratory or in the field would necessarily provide this opportunity, as there is a risk that, depending on several factors (e.g., the context of the research, the activities in which they actually engage, the ideology of the scientists with whom they are working), teachers may not be able to become fully engaged in the scientific community of practice. Lave and Wenger, for example, point out that communities of practice do not simply open information to newcomers: in many instances, they may constrain newcomers' opportunities to learn by restricting them from information or chances to participate authentically. It is an empirical question to what extent research experiences make learning opportunities available for teachers, or, alternatively, whether participants are restricted from access to participation and learning, and whether such learning opportunities are sufficient to impact teachers' views of and classroom instruction related to NOS. In this study I therefore investigate how participation in research and the scientific community of practice may impact teachers' thinking about NOS, as well as the implications of whether changes in this thinking may consequently lead to changes in their instructional practices related to NOS.

Teacher Engagement in Research

Several programs designed to provide in-service teachers with exposure to authentic research experiences currently exist nationwide, although these types of programs differ widely in both their focus and structure. The impact of some of these programs on their participants has been studied in varying degrees, yet few conclusions have been drawn about what elements of these programs might be most beneficial for teachers' thinking about science as a discipline. In general, these programs provide teachers with the opportunity to work on a research project, typically during summer break, with the aim of providing them with a hands-on experience in how scientific research occurs. These studies can be further characterized in two ways: (1) by the type of research setting in which the teachers participate; and (2) by the amount and forms of support provided to teachers outside the research experience intended to impact their classroom teaching. Each of these categories will next be explained and representative programs discussed in relation to each category.

Types of Research Settings

In the studies reviewed, the type of research settings in which teachers worked typically fell into one of two groups. Teachers either worked with researchers on a project that was part of an ongoing research agenda, or worked with other teachers and/or students under the guidance of a research scientist to complete projects that did not otherwise contribute to ongoing research. While each of these may afford teachers unique opportunities to experience research, it is worthwhile to consider whether one setting may be more constructive than the other in terms of building teachers' NOS understanding.

Of the 12 studies reviewed, six of them engaged teachers in research projects that were part of an ongoing research agenda. The programs described in these studies include a Physics Research Experience (Garofalo, Lindgren, & O'Neill, 1992), Science Teachers as Research Scientists (STARS; Gottfried, 1993), Science for Early Adolescence Teachers (Science FEAT; Spiegel, Collins, & Gilmer, 1995), Research Internship in Science/Mathematics (Fraser-Adler and Leonhardt, 1996), the Teacher Research Update Experience (TRUE; Barnes, Hodge, Parker, & Koroly, 2006), and a biomedical engineering Research Experiences for Teachers program (RET; Klein, 2009). In addition to some variation in the length of teacher engagement in research (e.g., five weeks for the Science FEAT and RET programs, six weeks for the STARS program, seven weeks for the TRUE program), other differences are evident in these programs. For instance, some of these programs, such as the Physics Research Experience and TRUE, required that, in addition to the time spent in their respective labs, teachers participate in other activities such as field trips (e.g., to other research facilities/sites) and attend lectures on topics relevant to their research. Furthermore, the participant in the Physics Research Experiences and participants in the Research Internship in Science/Mathematics were required to present their research to fellow participants and members of the research community involved in the program at the conclusion of their experience. Additional differences between these programs as described in study reports primarily centered on the forms of support provided to teachers outside of their research experience and will thus be discussed in the following section.

Four other studies of research opportunities for teachers describe programs that took quite a different approach from those previously described for engaging teachers in research. In each of these programs, teachers worked in teams on projects that were not part of an existing research agenda, but that were still overseen by research scientists. Instead, the teams typically created the projects themselves, or, as in one case (Hemler and Repine, 2006), projects were simply assigned to the groups by the program coordinators and were essentially the same across groups (i.e., constructing geologic maps of different regions within a state park). One study (Blanchard, Southerland, & Granger, 2008) suggested that a reliance upon program-specific projects (rather than couching the teachers' projects in ongoing research) was preferable based on the criticism that, if teachers joined existing research projects, "the activity may [have been] authentic to science but not authentic to the participating teacher" (p. 328).

In addition to some other disparities between these team-based research programs, such as differences in program length (ranging from two to six weeks) or the particular activities in which teams participated (e.g., giving presentations), one other feature stands out to distinguish between them further: the composition of the research teams. Two programs, GEOTEACH (Hemler and Repine, 2006) and the Marine Ecology for Teachers (MET) program (Blanchard et al., 2008) required that teachers work together on such teams. In contrast, the Nevada Science Teacher Enhancement Project (N-STEP; Buck, 2003) and a program described by Jeanpierre, Oberhauser, & Freeman (2005) required that teachers work alongside students in their research teams. According to the Jeanpierre et al., their program relied upon teacher/student teams in order to provide the teachers with opportunities to see firsthand how students dealt with complex science content and research.

In addition to the ten studies reviewed previously, two others described programs designed to expose teachers to scientific research, but failed to specify whether or not the teachers' experiences were part of an ongoing research agenda. Reports about both the Institute for Science Instruction and Study (ISIS; Haakonsen, Stone, Tomala, & Hageman, 1993) and the Teachers in the Woods Program (Dresner and Worley, 2006) indicate that teachers were partnered with research scientists to complete a research project, yet the origins of their research projects remain unclear.

Affecting Change in Teacher Thinking About and Enactment of Instruction

In addition to structural differences in terms of the types of research projects on which participants worked in the studies reviewed, the extent and form of support provided to teachers outside of their actual research projects to influence their thinking about teaching and classroom practices also differed across this same set of 12 studies. Some research experience programs were embedded in a broader course of study (e.g., advanced degree programs), while others functioned as stand-alone programs that did not directly attempt to influence teaching. Others fall somewhere in the middle of this spectrum with some limited support provided, typically in the form of curriculum development. Each of these categories is next discussed.

Three programs described in the reviewed studies incorporated a teacher research experience as part of a broader, longer-lasting set of activities aimed at improving science education. Two of these programs, ISIS (Haakonsen et al., 1993) and Science FEAT

(Spiegel et al., 1995), included a research element as part of a larger program that enabled participants to earn either a graduate certificate or a master’s degree, respectively. Consequently, the research portion of the program was embedded in a sequence of coursework or seminars that addressed a range of topics related to science education. For instance, teachers in the Science FEAT program completed summer courses in Data Collection and Interpretation; Science, Technology, and Society; and Philosophy of Science in the years immediately preceding and following their summer research experience. Although the N-STEP program (Buck, 2003) did not result in advanced certification or degrees, it was “embedded in a nine month program including a formal class sequence providing research context and pre- and post field research learning” (p. 48).

In contrast to these programs, others provided more limited types of support for impacting participants’ thinking about teaching. This support primarily took the form of the development of some form of curriculum based on teachers’ research experience that participants could then take back to and implement in their own classrooms. The specificity of the forms that this curriculum could take varied, however, as did the support provided to teachers as they implemented their lessons. For instance, the Teachers in the Woods program (Dresner and Worley, 2006), required participants to create field projects for their students and participate in workshops throughout the school year “to ensure transfer of new skills to the classroom” (p. 3). Similarly, the MET program (Blanchard et al., 2008) required that teachers adapt one of their existing curriculum units to make it more inquiry-based and therefore engaged teachers in a series of activities designed to help them think about inquiry-based instruction during the summer program. Teachers who participated in the RET program (Klein, 2009) wrote curriculum units utilizing a pre-determined lesson framework to help translate their research experience to the classroom. They were also required to meet as a group two times throughout the academic year to report on the status of their curriculum units. Other programs provided less long-term support to teachers in the development and implementation of their curricula. The STARS program (Gottfried, 1993) engaged teachers in curriculum workshops during the program, with the culmination resulting in the creation of a curriculum unit to take back to their classrooms. The Research Internship in Science/Mathematics (Fraser-Abder and Leonhardt, 1996), which was an elective internship available to master’s degree students at a university, also required participants to develop a curriculum unit for their students and asked participants to create an introductory video about their research for students as they began the curriculum. Neither of these last two studies reported any supports put in place to aid the teachers as their units were implemented.

Still other programs provided less-sustained or virtually no support to teachers for thinking about teaching or changing their classroom instruction. The program described by Jeanpierre et al. (2005) included time for teachers to discuss inquiry-based instruction and how their activities in the program might link to this teaching approach, yet there was not any clear-cut pathway through which teachers were expected to incorporate this into their own classrooms. Similarly, the TRUE program (Barnes et al., 2006) provided participants with opportunities to discuss teaching strategies and lessons with one another throughout their research, but also did not require that this be translated into their instruction in any way. The final two studies reviewed (Garofalo et al., 1992; Hemler and

Repine, 2006) did not provide opportunities for participants to talk about their teaching, nor did they require participants to create any product based on their research experience to take back to the classroom.

Discussion of Research Experience Programs and Related Study Findings

While the particular activities in which teachers participated during the research experiences described in these 12 studies varied based on the particular requirements of their program and the research setting in which they worked, the overall structural differences in terms of their research project context and the forms of support provided outside their research provide the most stark contrast between these programs. In spite of these structural differences, each of these programs aimed to improve teachers' understanding of science. Surprisingly, though, very little research has been done to determine the effects of these teacher research experiences on individuals' NOS understanding. This is the case even for those studies in which the researchers made specific claims about how the teachers' experiences would help develop teachers' conceptions of NOS (e.g., Fraser-Adler and Leonhardt, 1996). With few exceptions (e.g., Spiegel et al., 1995, which unfortunately does not report on many of their findings), those studies that do address teachers' conceptions of NOS and/or the impact of programs on classroom practices rely primarily on self-report. Clearly further research is needed to comprehend how participation in research may impact teachers' NOS understanding and their classroom instruction related to NOS more fully.

The need for further investigation of the impacts of these types of programs is further underscored by a comprehensive review of studies of research apprenticeships available to secondary students, undergraduate students, pre-service teachers, and in-service teachers conducted by Sadler et al. (2010). The six studies of programs designed for in-service teachers that were reviewed by the authors revealed that only one documented gains in teachers' NOS understanding, while another documented limited or no gains in this understanding. Furthermore, minimal efforts were made in these studies to determine whether changes in NOS understanding were reflected in classroom practice. The authors pointed out that none of these studies included any form of classroom observation to document potential changes in instruction and instead relied on self-report from program participants about whether their instruction had changed. The authors concluded with a call for more rigorous methodology when conducting research into these programs. They also stated a need for closer examination of the affordances of particular elements of different programs, as they thought "that finer grained analysis of specific programmatic features would yield additional insights that might be leveraged by…designers and managers who conceptualize and run these projects" (p. 253).

Research on the effects of science teacher research experiences has made some contributions to understanding how these programs impact teachers; however, this literature is deficient in adequate measurement and analyses of how these experiences contribute to the development of teachers' understanding of NOS and the extent to which this understanding is carried into the classroom. Short-term and longitudinal studies that utilize more extensive instrumentation, including carefully-designed NOS surveys and interviews as well as pre- and post-program classroom observations of teachers' instructional practices, would better inform researchers about the impact of these programs on teachers' classroom practices related to NOS. Research addressing this development, such as that described below, would provide insight into the design of effective professional development programs that promote teacher understanding, and that, in turn, may enhance student learning.

CHAPTER III

METHODOLOGY

Context of the Study

Based on the lack of emphasis placed on the development of teachers' understanding of NOS in previous studies of teacher research experiences, particularly in relation to the reconceptualized NOS framework described earlier, further research into the impact of these experiences is warranted. Furthermore, the studies described above generally fail to explore the extent to which teachers' instructional practices may change as a result of their participation in authentic scientific research. This study therefore seeks to investigate the impact of participation in research, both on participating teachers' conceptions of the nature of science and their classroom instruction related to NOS. Consequently, the following research questions are investigated:

(1) To what extent does participation in research through an engineering-based summer program affect teachers' understanding of NOS?

(2) Are patterns evident in aspects of or activities within teachers' research experiences that suggest that they may help promote changes in teachers' NOS understanding?

(3) Do teachers' classroom instructional practices change to reflect new conceptions of NOS?

Context for Participation in Research

Sponsored by the National Science Foundation (NSF), Research Experiences for Teachers (RET) in Engineering provides in-service (and, in some cases, pre-service) secondary teachers with opportunities to participate in research and also focuses on incorporating these research experiences into classroom instruction. Vanderbilt University (Principal Investigator: Stacy Klein-Gardner) has hosted RET summer programs for middle and high school science, technology, engineering, and mathematics (STEM) teachers during the summers of 2004 through 2012. The research component of the program involves teacher participants in various subfields of engineering research. According to the NSF (2007):

> [the] Research Experiences for Teachers (RET) in Engineering program supports the active involvement of K-12 teachers and community college faculty in engineering research in order to bring knowledge of engineering and technological innovation into their classrooms. The goal is to help build…collaborative partnerships between K-12 science, technology, engineering, and mathematics (STEM) teachers, community college faculty, and the NSF university research community by involving the teachers in engineering research and helping them translate their research experiences and new knowledge of engineering into classroom activities. (Synopsis, para 1)

Through collaboration with research professors in the Vanderbilt Medical Center and the School of Engineering, teachers complete small-scale research projects that are part of a professor's broader research agenda.

As noted previously, Klein (2009) presented findings from a study of three years of RET summer programs. A total of 42 teachers participated in biomedical engineering research and created curricula based on their research activities. (A detailed description of this program can be found later in this document to contextualize the current study of participants' research experience.) Prior to and following their participation in the RET program, teachers completed surveys addressing their attitudes toward several topics of interest, including the relevance of scientific research to the classroom, teachers' confidence in their own content knowledge for teaching, and the value of the Legacy Cycle approach toward instruction, as described by Bransford, Brown, & Cockings (2000) and introduced during the summer program. (Although Legacy Cycle-based instruction is not a focus of the study proposed here, it provides a framework for creating a curriculum unit that requires students to share their existing knowledge about a real world contextually-based challenge topic, learn more about the topic through a variety of instructional activities decided upon by the teacher, assess their own understanding of the topic, and ultimately demonstrate their mastery of the topic, often by responding directly to the challenge question in a format chosen by the teacher.)

The pre- and post-program attitude survey consisted of 13 statements that participants rated using a Likert-type scale. Comparisons of average total survey scores for all participants on the pre and post-surveys revealed that scores increased following participation in the RET program, indicating that their attitudes about the topics addressed in the survey improved in that time. However, it is also noted that "most of the total increase [in average pre and post-survey scores] came from an increase in the questions related to the use of the Legacy Cycle [method of instruction]" (Klein, 2009, p.

529). Increases in scores were also found in relation to teachers' views of the relevance of scientific research to the classroom, as well as their confidence in their content knowledge. The author further claims that "RET teaching strategies are now more likely to include the types of activities that are found in true scientific research" (p. 530). It is important to note, however, that, as with other studies described previously, these conclusions are based solely on teacher self-report on pre- and post-program surveys. The author acknowledges the limitations of survey data and also indicates a need to tease apart the impact of some of the RET program's components from that of the actual lab-based research experience. A related study conducted by Klein-Gardner, Johnston, and Benson (2012) investigating the impact of the research-based curriculum units produced by RET participants similarly reports positive outcomes from the RET program for "increasing [teachers'] confidence in using a learning cycle as the basis for instructional design" (p. 33). Given that this study relies on interview data to learn about participating teachers' classroom instruction, the authors acknowledge the potential value of observations of instruction to explore what is occurring in the classroom more thoroughly. It is precisely these issues, as well as those raised by other studies of similar programs, that are addressed in the study proposed here.

Study Setting

The proposed research questions are investigated through a study of science teachers who were accepted to and participated in the RET program for the first time during one iteration of the summer program. Although the stated goals of the RET program do not directly address NOS, and the teachers' research experiences are grounded in engineering rather than the science disciplines in which most of them teach, this study investigates whether teachers' understanding of NOS will change as a result of their participation in research through the RET program, and whether changes in this understanding will influence their classroom instruction related to NOS. Therefore, we do not conceive of this study as an evaluation of the RET program, but as investigation of the impact of participating teachers' experiences working in a research laboratory. A familiarity of the overall layout of the RET program is, however, necessary to understand the context within which the teachers' research experience is situated.

Program participant selection. STEM teachers are recruited to the RET program at Vanderbilt University through program websites and direct contact with schools. These recruitment efforts are focused on teachers in public and private middle and high schools within driving distance of the university, as housing is not provided to participating teachers. Teachers are required to apply to the program in teams (i.e., at least two teachers from one school) in order to "promote team-teaching and intra-institutional support" (S. S. Klein-Gardner, personal communication, November 19, 2009), and teams may consist of individuals who teach in different STEM disciplines. For example, a math teacher and a science teacher may form a team from one school. Also, because teachers from previous years may apply to participate in the RET program for a second or third summer, teachers who are new to the program may team with veteran RET teachers.

The following criteria are considered for admission to the program:

> Teacher participant teams [are] selected based on several factors: their statement of why they want to attend, their institutional support demonstrated through a

> letter of recommendation from a department chair or principal, the demographic make-up of the school, their willingness to share their knowledge and spread the materials at their home school and beyond, geographic diversity of applicants, racial and gender diversity of applicants, and the experience level of applicants. (S. S. Klein-Gardner, personal communication, November 19, 2009)

Final decisions about admission are made by the program director, Dr. Stacy Klein-Gardner.

Study participants. The proposed research questions were investigated through a study of high school science teachers who participated in the RET program for the first time during the year studied. Six teachers from four different schools participated in the study (all of the first-time science teacher participants during that summer). Detailed information about the participants' educational, research, and teaching backgrounds can be found in the *Methods* section.

RET program overview. Over the course of six weeks, participating teachers progress through three overall phases of the RET program. The first three days of the program serve as an introductory period. Teachers become acquainted with one another, listen to a series of lectures on current studies in engineering presented by research faculty, and are trained in teaching one existing engineering-based curriculum unit that had previously been developed by the RET Program Director. During this training, teachers become acquainted with the Legacy Cycle method of instruction, as they are expected write their own curriculum unit based on their research experience using this framework at the end of the RET program and then implement this unit the following academic year.

Following this initial phase, teachers begin working full-time in their research laboratory placement. Although teachers are required to participate in the program along with another STEM teacher from their school, individuals work separately in different laboratories during their summer research. Participants are matched with research mentors based on their interest in the professor's ongoing research agenda and the extent to which it relates to the courses that they teach during the academic year. The research activities in which the teachers participate vary depending on the focus of the lab in which they are working and their individual project. Typically, participants' projects are identified in advance of the program by the research mentors. Although these projects are relatively small in scale so that teachers may complete them during the research portion of the RET program, they are generally intended to contribute to the lab's overall research goals. All participating teachers meet weekly for lunch to discuss their work informally and foster acquaintance with other program participants. During their time in the lab, teachers are also asked to begin thinking about how they might incorporate aspects of their research topic into the curriculum unit that they will develop later for use in their own classroom.

During the final three days, teachers reconvene to work on writing their curriculum units, which they are required to teach in one of their classes at some point during the following academic year. Klein-Gardner et al. (2012) describe the intent of these curricula as follows:

> These units are intended to be substitute units for the way the teacher traditionally taught the topic, so as not to add content that there is no time to cover, and also allows the teacher to introduce engineering to their students… Teachers are

> encouraged to bring scientific inquiry and engineering design into their classrooms after having the opportunity to develop these skills and improve their own confidence during their research placement. (p. 27)

The Program Director is available throughout the curriculum writing process to provide guidance and feedback on these units, as well as to aid in the development of pre- and post-unit assessments to evaluate curriculum effectiveness as needed. Teachers must submit their completed curricula to the Program Director by the end of April following their participation in the RET program; curricula meeting content and formatting requirements are submitted for inclusion in a web-based digital library of engineering curricula designed for and made freely available to K-12 educators.

In addition to any informal interactions that may occur between RET teachers during the six-week program, the teachers convene weekly for a whole-group lunch. According to Klein (2009), the weekly lunches are intended "to encourage the growth of a community. These lunches were time for sharing accomplishments and frustrations in the lab along with time to discuss teaching as a whole" (p. 525). Therefore, both informal and lunch-centered forms of interaction provide teachers with opportunities to get to know one another better, as well as potentially discuss their ongoing work and/or teaching.

Focal NOS constructs and theory of change. Although I maintain that it is ways in which *all* the components of my NOS framework relate to one another and converge to influence the scientific community of practice that truly constitutes NOS, and it is believed that participation in research may help teachers improve their understanding of and classroom instruction related to NOS, it is possible that some aspects of NOS understanding may be more susceptible to change than others as a result of such experience, particularly depending on the type of research setting in which a teacher is placed. Before considering these focal constructs, though, it is worth noting that there are important aspects common to programs such as the one studied here that one might anticipate regardless of the research setting. For instance, it is reasonable to expect that participants in these types of research experiences would begin their time in the lab as an observer of researchers' activity (both physically and possibly through reading scholarly work produced by the lab and/or related background material) in order to provide them with the opportunity to become acquainted with lab norms and procedures. Given that the intent of research experience programs such as the one studied here is to engage teachers in the actual research process, the teachers would then transition to increasing levels of participation in the day-to-day activity of the lab in which they worked. Therefore, those who participants were able to progress further along the trajectory from observer of to participant in activity would have had a more authentic experience that more closely resembled the typical activities of professional researchers, and consequently would be more likely to have experienced richer opportunities for change toward more sophisticated understandings of NOS, as they would have been more fully engaged in the scientific community of practice overall.

Of those study participants who *do* exhibit change in their sophistication of their conceptions of NOS, we must then consider how this new understanding might be reflected in their thinking about and enactment of classroom instruction. Those who maintain less advanced understandings of NOS may identify connections between their research and teaching primarily by importing content, materials, or instruments from the research context into instruction. They may not problematize the nature of science, either for themselves or for their students, but may instead focus on surface feature similarities between what they encountered in the program and what they present to their students. While those who develop more sophisticated NOS appreciation might also make these types of connections between their research experience and the classroom, they may also be better equipped to consider approaches to instruction that would more closely reflect the norms and practices of professional science that they, themselves, experienced. Although it is not possible to recreate an academic research environment in K-12 classrooms completely, those individuals who exhibit more advanced understandings of how NOS can be addressed in the classroom could describe innovative ways in which they could organize instruction to reflect certain aspects of NOS (e.g., with respect to how students work together, or the types of tasks presented to students) and how engaging students with such activity could further their NOS understanding.

Although it was not explicitly designed to effect change in relation to participants' NOS understanding, certain features of the Vanderbilt University RET program in Engineering studied here may highlight some aspects of the scientific community of practice and therefore provide opportunities for change in participating teachers' NOS understanding. Of course, engineering may highlight some aspects of NOS but fail to incorporate others because of the patterns of similarity and difference between the fields of science and engineering. As noted in the *Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012):

> Engaging in the practices of science helps students understand how scientific knowledge develops; such direct involvement gives them an appreciation of the

> wide range of approaches that are used to investigate, model, and explain the world. Engaging in the practices of engineering likewise helps students understand the work of engineers, as well as the links between engineering and science. Participation in these practices also helps students form an understanding of the crosscutting concepts and disciplinary ideas of science and engineering. (p. 42)

Although these remarks focus on the development of these understandings in students, these ideas are relevant for thinking about how teachers come to understand science and engineering. While points of contact between the practices of these two fields exist, these crosscutting concepts (NRC, 2012) may look different depending on whether one is considering them through a science or engineering lens. Consequently, in relation to the NOS framework presented earlier, five constructs were selected for focus during this study that are believed to be mostly likely subject to change in terms of teachers' understanding of and instruction related to NOS as a result of participation in this particular engineering-based RET program. These focal constructs and their sub-components selected for study are highlighted in green in Figure 2 and subsequently discussed in relation to teachers' potential research experiences and possible opportunities for change with respect to their NOS understanding and instruction.

Nature of Science:

Science as a Community of Practice

Social Structures

Construction and Critique of Claims

- *Scientific argument*
- *Discursive norms*

Intellectual Interdependence

- *Intra- and interdisciplinary exchange*

Products and Goals of Science

Variability of Methodology

Scientific Knowledge

- *Generative*
- *Co-constructed*
- *Tentative/subject to change*

Modeling and Inscribing

- *Types of models*

Science as a Human-constructed Endeavor

Historical & Contemporary Context

- *Beliefs and values*
- *Creativity*

Figure 2. Focal constructs of the reconceptualized NOS framework. Focal constructs are highlighted in dark green and subcomponents selected for study in light green.

Intellectual interdependence: Intra- and interdisciplinary exchange. This construct was selected for investigation in part due to the inherently interdisciplinary nature of the engineering-related laboratories in which the teachers worked. All study participants were placed in labs either within the School of Engineering or within the Department of Radiology and Radiological Sciences of the Vanderbilt University Medical Center, therefore these labs' research agendas regularly cut across disciplines (e.g., anatomy and medical imaging). There is, therefore, potential for the teachers to engage with researchers who specialized in vastly different science and/or engineering disciplines, yet who work together toward common research goals. It is believed that this exposure may aid teachers in comprehending the interconnectedness among diverse fields, including the science disciplines taught in their classrooms. Should a teacher work on a relatively isolated project that requires little interaction with other researchers and/or researchers from different disciplines, however, this potential for change may remain untapped. It is therefore important to consider the types of research activities in which each teacher participates and the individuals with whom they interact in completing their projects to account for these potential differences.

With regard to classroom instruction, teachers who possess a more sophisticated understanding of NOS may more strongly emphasize the intra- and interdisciplinary nature of science and engineering research. For those with more sophisticated understandings of NOS, this might be visible through lessons that draw upon several domains of science, such as an activity in a biology class that requires familiarity with aspects of physics and/or chemistry, while those with more limited NOS understanding might only require students to become knowledgeable about certain aspects of a topic within a single discipline. These types of activities could be confined to an individual class, in which students are asked to consult sources (e.g., books, websites, researchers) about different aspects of a topic, or could even involve collaboration among students enrolled in different courses (e.g., students enrolled in a biology class working with students in a chemistry class). The knowledge acquired by each student about his or her respective topic could then be shared and assembled with their peers' specialized knowledge to address a common learning goal. In contrast, teachers who do not appreciate the interdisciplinary nature of research would fail to emphasize how the various domains interact to influence one another, and how collaboration even within a single domain is useful to move research forward, as scientists rarely work in isolation.

Variability of methodology. It is expected that a research experience grounded in engineering may help teachers understand that research takes place through many different avenues and not through one fixed, universal scientific method. Through potential exposure to different forms of scientific research (in large part due to the interdisciplinary nature of engineering research, as described previously), teachers may come to question the validity of the "scientific method" stereotype. As noted for the previous construct, however, the potential for change of teachers' understanding may be impacted by their individual research experiences. For example, if a teacher's activities primarily involve following an experimental protocol that is highly-structured with little room for variation or innovation, he or she may not come to question the idea of a universal scientific method in the same way as a teacher who has more methodological freedom in how they conduct their research project (or, for that matter, a teacher who is working in a lab that is struggling to develop or validate a new model of a phenomenon or process). Furthermore, those participants who are placed in labs focused primarily on engineering design may gain more insight into the methods associated with that process rather than NOS. While valuable for understanding the field of engineering, it is not the focus of this study. Those teachers who do possess an understanding of the variation that exists in how scientific research is conducted may be more likely to encourage their students to develop their own approaches for answering questions and allow methodological flexibility as they do so. As their understanding of NOS becomes more sophisticated, these teachers may become increasingly likely to include such approaches to instruction. Teachers with a lesser understanding of this idea might rely on lab activities that are highly scripted, follow a more regimented, scientific method-based approach, and which allow for little (if any) variation in how the students go about completing the activity.

Scientific knowledge: Generative; Co-constructed. Given that teachers participate in projects related to ongoing work in researchers' laboratories, it is expected that teachers may better come to appreciate the idea that research is primarily aimed at generating new or refining existing knowledge rather than verifying it. This is due to the fact that the teachers' research activities may be aimed at generating new data to evaluate the validity of hypotheses that were (and possibly still are) being investigated, rather than collecting data intended to corroborate existing knowledge. This assumption is based on the understanding that teachers' projects are designed and intended to contribute to their mentor researchers' ongoing research agendas. In the event that a teacher's research is focused more on verification, the potential for growth in their understanding may be limited. It is also possible that, if working in an engineering design environment, the development of new knowledge may not be clearly visible to teachers, particularly as researchers work through the process of testing their design. New understandings of strengths and weaknesses of the design may develop as a result of these tests, but this may not be construed as driving the generation of new knowledge, as a repeated testing process could be viewed as a verification-driven process.

A shift from a less-sophisticated understanding of this aspect of NOS to a more refined view might be indicated in classroom instruction by a transition from activities (such as labs) that require students to obtain pre-determined results to verify an existing concept, to those that are more open-ended and allow students to generate their own understanding of a natural phenomenon. This understanding may then change with further exposure to the phenomenon to align more closely with the accepted scientific explanation for it.

As noted in the initial description of my NOS framework, the co-construction of scientific knowledge is closely tied to *Intellectual Interdependence* in science. Therefore, teachers who have more opportunities to interact with and build knowledge about a particular phenomenon through their research are more likely to develop sophisticated notions about the co-constructed nature of scientific knowledge. The potential variation in teachers' experiences with regard to both this and the generative nature of scientific knowledge again underscores the need for careful tracking of each teacher's individual research experience. With respect to classroom instruction, an understanding of NOS more closely aligned with my framework could be reflected in certain activity structures that encourage students to work in groups toward a common goal. Collaborations such as those described for communication of the idea of *Intellectual Interdependence* in science, in which students provide expertise on a concept from different disciplinary perspectives, might be more valuable for students' understanding than, for example, simply having students work together to complete a set of prescribed, recipe-like lab activities.

Modeling and inscribing: Types of models. With respect to the teachers' understanding of the types of models used by scientists, change might be visible due to the potential variability of modeling strategies employed in their research settings (e.g., mathematical models, computer-based models, scale models, etc.) Differences in the ways in which these types of models might be used in engineering research when compared with science research must be considered, however. While models in engineering may take similar forms as in science research, the ways in which they are used (e.g., to test a design) may differ. The extent to which a research experience might help teachers think about models in these ways would largely depend on the type and variety of modeling activities in which they engage. Therefore, it would again be important to account for individual differences in the teachers' research experiences with respect to modeling. Classroom instruction that would reflect more sophisticated views of modeling in science would help students understand that the purpose of scientific research is to model the natural world in some way, and that this may be done in a variety of ways depending on the norms of different science disciplines (e.g., structural or scale models, mathematical models, experiments as models, etc.). This might be accomplished by engaging students in the creation and use of different forms of modeling while highlighting the idea that the intention is to model natural phenomena, even if, aesthetically, the models do not appear to resemble these phenomena. Shifts toward this more sophisticated approach to modeling would be expected to become visible as individuals develop more advanced understanding of this aspect of NOS.

Historical and contemporary context: Beliefs and values. As noted previously, the focus of scientific research is often driven in large part by societal needs, which may effectively play roles in the types of projects that receive monetary funding and institutional support. Given the applied nature of engineering research, it is believed that the influence of contemporary societal needs may be especially evident. This influence may be communicated to teachers throughout their research experience based on the types of projects in which they are involved, and so their understanding of the impact of the surrounding context on the scientific community of practice is expected to become more refined. Because there may be some variation in the extent to which teachers are exposed to ideas about the overall influence of societal needs on research, differences may exist in the extent of the changes in their understanding based on what they may learn about project funding and selection from the research colleagues with whom they interact.

Those teachers who do appreciate the contemporary influences on scientific research might require students to consider how societal views impact the types of research being done, as well as how it is conducted. Others with even more sophisticated conceptions of this aspect of NOS might take this one step further and ask students to consider how economic concerns might factor into what types of research are pursued and explore the ways that funding influences different research programs in different scientific disciplines. This could be done in a number of ways. For example, teachers might ask students to propose hypothetical research projects and ask them to justify why their project should be considered for funding from government of private institutions.

Summary of potential for change. Overall, it would be expected that those participants who were able to participate more frequently and authentically in the aspects of the scientific community of practice addressed through the focal NOS constructs would be more likely to develop more sophisticated conceptions of those aspects of NOS. That is, those who had opportunities to both witness and engage in multiple forms of intellectual exchange, work on different aspects of a project that utilized different methodologies for investigation, work to develop new knowledge in the field through co-construction with other researchers, engage in different forms of modeling, and/or were exposed to the manner in which beliefs and values may influence research would be afforded richer opportunities upon which to build their NOS understanding in relation to one (or more) of these focal constructs and consequently increase the likelihood that more sophisticated conceptions of NOS would be visible in their classroom instruction. Those who participated in these aspects of NOS more peripherally or who lacked exposure to such activities would therefore be less likely to experience opportunities for change.

Study Methods

Participants

Recruitment. As noted previously, all six science teachers accepted by the RET Program Director into the summer program for the first time in the year studied were selected for recruitment into this study. This study was conducted in two sites: teachers' own classrooms and the RET program site. For logistical reasons, teachers' participation was requested separately for these parts of the study. I applied for and received IRB study approval and subsequently received approval for the study from the two public school districts in which five of the participants taught. (The sixth participant taught in a private school, therefore district approval was unnecessary.) Upon receiving these approvals, the principals and/or director of each of the schools in which the six participants taught were contacted to seek access. The researcher met with the principal, assistant principal, or director of each school on-site to discuss the study and obtain written permission to conduct observations in their teachers' classrooms. Each teacher recruit was then contacted and asked to meet with the researcher to discuss their potential participation in the instruction-based portion of the study. During each meeting, the researcher described the study procedures and reviewed the informed consent document with prospective participants. All six teacher recruits agreed to participate.

Approval for the summer-based portions of the study was later received through an amendment to the original IRB application. The researcher met again with each of the six study participants at the beginning of the summer RET program to discuss this portion of the study. Study procedures were again reviewed, as was a revised informed consent document. Each participant agreed to participate in the summer-based portion of the study.

Participant overview. A summary table highlighting the differing educational, research, and teaching backgrounds of participants is provided below (Table 2). Information about participants' educational and research background was collected to understand their previous exposure to science, especially research and in what form(s), as this likely influenced their NOS understanding prior to their participation in the RET program. Teaching background was documented to gain insight into differences in the extent of participants' teaching experience, since this may have impacted their views on the types of classroom instruction that are most effective for communicating ideas about science as a discipline and their willingness to alter their instruction based on any new understanding of science they may have acquired through their current summer research. Information about the schools in which each participant taught and the specific classes they taught at the time of this study was documented to contextualize participants' teaching environments. This information was considered important for understanding the institutional constraints (e.g., curriculum, state-mandated assessments, material resources) that may have influenced teachers' instruction. As Table 2 shows, teachers varied considerably in their teaching experience (from one to 35 years; most participants had around five years of experience) and the science courses for which they were responsible (about half taught courses in the life sciences and half in the physical sciences and/or engineering).

Table 2

Overview of Study Participants' Educational and Teaching Background.

Teacher ID	Educational Background	Prior Research Experience	Years of Teaching Before RET Program	Teaching Setting	Courses & Grade Levels: School Year Preceding RET Participation	Courses & Grade Levels: School Year Following RET Participation
T1	BS in Education in Math and Related Science	Some prior research with another local university[a]	32	Private K-12 institution	Physics; Pre-engineering Grades 10-12	Physics; Pre-engineering Grades 10-12
T2	Bachelor's degree in Biology Teaching	N/A	1	Public high school; suburban	Life science; Anatomy & Physiology Grades 9-12	Biology; Anatomy & Physiology Grades 9-12
T3	Bachelor's degree in Biology; Master's degree in Biology	Some course-based research during Master's program[b]	4	Public high school; suburban	Biology Grades 9-12	Biology; AP Biology Grades 9-12
T4	BS in Chemical Engineering	N/A	8	Public high school; suburban	Physics Grades 9-12	Physics Grades 9-12
T5	Bachelor's degree in Multidisciplinary Studies; Master's degree in Secondary Education	Some research as part of Master's program[c]	5	Public high school; suburban	Physical Science Grades 9-12	Physical Science Grades 9-12
T6	BA in Zoology; Master's degree in Education	N/A	4	Public high school; suburban	Biology; Ecology Grades 9-12	Biology; Anatomy & Physiology Grades 9-12

[a] T1 has participated in scientific research at another local university, partnering with an education professor to help work with students to use data to investigate patterns in star intensity. He has also participated in professional development programs aimed at increasing content knowledge of particular science content (i.e., particle physics at the Fermi lab) and/or curriculum development (i.e., teaching astronomy using image processing) linked to research, although neither of these experiences involved any hands-on scientific research. [b] While completing his Master's degree, T3 participated in some course-based scientific research. [c] T5 conducted research investigating the relationship between student involvement in athletics and academic achievement while working on his Master's degree.

Phases of Study

The study consisted of three major phases: (I) Pre-program Classroom Instruction; (II) Within-program Activity; and (III) Post-program Classroom Instruction. The timing and research instruments used during each of these phases are described briefly here to provide the reader with an overview of the progression of the study. The individual instruments and methods employed in each phase are subsequently described in greater detail in the *Measures* section.

Phase I: Pre-program classroom instruction. The first phase occurred in teachers' classrooms prior to their summer research experience. This phase focused on the baseline ways in which teachers' NOS understanding were reflected in their classroom instruction, and thus addressed the third research question. I observed participating teachers during their regular classroom instruction prior to their involvement in the summer session during *Instructional Observations*. The purpose was to identify and characterize the ways in which teachers verbally or implicitly communicated ideas about NOS throughout their classroom instruction. At the conclusion of this set of observations, teachers participated in an individual *Instructional Interview* about their teaching. During this interview I asked teachers about specific events observed by the researcher and also about other typical instructional practices. Teachers were also asked about their more general views on science teaching, which may not have been revealed through discussion of their own practice.

Phase II: Within-program activity. This phase of data collection was designed to answer the first two research questions and occurred during the summer RET program. Immediately before beginning the RET program, participants completed a *Pre-research*

NOS Questionnaire to assess their understanding of the nature of science. They then participated in individual semi-structured *Pre-research NOS Interviews* to explore further this understanding immediately prior to their participation in scientific research. These interviews were conducted one-on-one with the researcher. Once they began conducting their scientific research, teachers were asked to keep detailed records of their activities in *Daily Activity Logs* and to write *Weekly Reflections* about their experiences. In addition, they participated individually in semi-structured *Bi-weekly Activity Interviews* with the researcher during their research experience to further catalogue their daily activities and to provide a check on the accuracy and completeness of the records in their *Daily Activity Logs*. On alternating weeks (that is, when not participating in *Bi-weekly Activity Interviews*), I visited the teachers in their labs and observed their activity during *Bi-weekly Laboratory Visits*. The purpose of these visits was to verify the accuracy of the teachers' *Daily Activity Logs* by providing me with a first-hand view of their typical research activities. At the conclusion of the research experience, each teacher completed a *Post-research NOS Questionnaire* (identical to the *Pre-research NOS Questionnaire*) and, immediately thereafter, participated individually in a *Post-research NOS Interview*.

Phase III: Post-program classroom instruction. In order to compare teachers' pre-program and post-program classroom instruction related to NOS, I conducted additional *Instructional Observations* of each teacher's classroom teaching following participation in the RET summer program. These observations took place during teachers' regular classroom instruction, as well as during the curriculum unit that they developed based on their research experience. As in Phase I of the study, upon completion of the entire set of observations, teachers participated in a semi-structured

Instructional Interview in which they discussed their views on science teaching and their own instruction.

Table 3 provides an overview of the timeline and the activities that took place during each phase of the study in order of their occurrence.

Table 3

Data Collection Timetable in Order of Study Progression

Phase	Activities	Timeframe
I: Pre-program Classroom Instruction	a) 2-3 Instructional Observations of classroom teaching	April-May
	b) Instructional Interview (upon completion of all observations)	
II: Within-program Activity	Program introduction: a) Pre-research NOS Questionnaire b) Pre-research NOS Interview	June-July
	Research placement: a) Daily Activity Logs b) Weekly Reflections c) Bi-weekly Activity Interview d) Bi-weekly Laboratory Visit	
	Program conclusion: a) Post-research NOS Questionnaire b) Post-research NOS Interview	
III: Post-program Classroom Instruction	a) 3-5 Instructional Observations of regular classroom teaching	August-May
	b) 3-5 Instructional Observations of classroom teaching during research-based curriculum unit	
	c) Instructional Interview (upon completion of all observations)	

Measures

As explained previously, the research questions addressed in this study include the following: (1) to what extent does participation in research through an engineering-based summer program affect teachers' understanding of NOS?; (2) are patterns evident in aspects of or activities within teachers' research experiences that suggest that they may help promote changes in teachers' NOS understanding?; and (3) do teachers' classroom instructional practices change to reflect new conceptions of NOS? This study consequently focuses on how participation in the research program may have affected teachers' understanding of the nature of science and, if so, how those changes in conceptions might have affected their classroom teaching. Of particular interest are teachers' understandings of the five focal NOS constructs: (1) *Intellectual interdependence in science (*especially the subcategory *Intra- and interdisciplinary exchange)*; (2) *Variability of methodology*; (3) *Scientific knowledge (*especially subcategories *Generative; Co-constructed)*; (4) *Modeling and inscribing (*especially subcategory *Types of models)*; and (5) *Historical and contemporary context (*especially subcategory *Beliefs and values)*. Therefore, it was important to establish the extent to which teachers were exposed to experiences that might impact their thinking about each focal construct. Second, I sought to learn if the teachers' thinking in relation to each of these aspects of NOS actually changed to reflect views more consistent with my NOS framework. The final issue is, given any such changes in their thinking, were these changes also reflected in teachers' classroom instruction? The measures employed in each of the three phases of the study, along with their purpose in the study, are next explained, each in turn.

Phase I: Pre-program classroom instruction. As noted previously, two primary measures were utilized during this phase of study: *Instructional Observations* of teachers' classroom teaching related to NOS and *Instructional Interviews* about the lessons observed and teachers' views on science teaching.

Instructional observations. Participants were observed in their classrooms during no fewer than two and no more than three lessons prior to the summer research program. Each observation lasted approximately 50 minutes, although some class periods were longer or shorter, depending on a particular school’s schedule. For these observations, teachers were asked to select lessons that they felt would help students understand science as a discipline. This was not always possible, however, because the observations fell fairly late in the school year (some immediately preceding a state-mandated end-of-course test and/or final exams) and because of other scheduling constraints on participating teachers. Teachers were asked to conduct their lessons as they normally would, without any alteration to their typical instruction.

These observations were intended to provide a baseline of understanding how the participating teachers’ conceptions of NOS were reflected in their instruction. The goal was to observe the teachers’ instruction directly, rather than relying on self-report of participants (teachers’ self-reports would be independently pursued in interviews, as I explain next), to obtain a snapshot of the types of instructional activities typically employed by each teacher. This allowed me to ascertain the ways in which teachers talked about science and related content with their students, which may also provide information about how their views of NOS are incorporated into their teaching. Furthermore, the researcher looked for the instructional approaches employed in each lesson (e.g., lecture, structured lab activities, inquiry-based activities, class discussions, textbook work) and the social organization of these activities (e.g., individual work/small groups/whole class, directions provided, roles of students and teachers, materials provided) to explore what types of conceptions of NOS may be implicitly conveyed to students. The nature of the content communicated through each lesson (e.g., discipline-specific information versus interdisciplinary content, expressed both verbally by the teacher and through course assignments) was also noted.

Lessons taught by T1, T2, and T3 were video-recorded and field notes were generated based on the recordings. Permission constraints necessitated that video footage and observations focus solely on teachers' instructional strategies during these lessons, therefore only students' voices were captured via audio footage as they interacted with the teacher. Due to county policy constraints, lessons taught by the remaining study participants could not be recorded; however, field notes documenting these lessons were generated by the researcher. Artifacts collected during observations were limited primarily to materials provided to the researcher by the teachers (e.g., handouts, worksheets) and were intended to ensure a thorough record of the instruction that took place during each observed lesson. Teachers were asked to provide copies of any materials distributed and used by students during these lessons, particularly those used as a basis for discussion or group activities, so that the researcher could more effectively follow the progression of each lesson and provide a richer qualitative description of each participant's instruction.

Instructional interviews. Semi-structured follow-up instructional interviews (see Appendix A) were conducted on another day soon after the conclusion of pre-program classroom observations in order to probe teachers' thinking about the structure and nature of their classroom activities, their reasoning for employing certain instructional approaches in their teaching, and their reasoning for addressing specific content. Interviews were conducted individually with each teacher at a time when students were out of the room. Before beginning the interview, I informed the participant that I would be asking them about their views about science education, the lessons that I had observed, and other typical classroom practices that may not have been observed during the selected lessons. Teachers had also been asked in advance to bring copies or descriptions of a lab or classroom activity that requires that students work in a way that most closely reflects how scientists think and work. Participants were asked to answer each question as completely as possible, were informed that it was alright if they were unsure about an answer to any question, and that there were no right or wrong answers. In the event that a participant did not have an immediate response to a question, he or she was provided time to consider the question further and was encouraged to make a best effort to try to answer the question.

The interview focused primarily on teachers' views about science education (e.g., the value of more structured versus less-structured laboratory activities), as well as their perspective about the types of instruction they considered most effective for helping students understand science as a discipline. The questions about science education were designed to obtain information about participants' views on types of instruction or science content that may be more or less aligned with the practices of the scientific community and/or may differ in their effectiveness of communicating accurate depictions of NOS to students. For example, to target teachers' ideas about modeling in science, they were asked to explain whether they did any activities with students that would help them understand how models are used in science disciplines, and whether the ways in which models are generated and used in the classroom are similar to or different from how scientists generate and use models. The interview also afforded the opportunity to discuss participants' typical classroom practices beyond those observed, as the researcher recognized that the limited number of observations may not have permitted a complete profile of the teachers' typical classroom practices.

In addition, the types of instructional strategies employed during the observed lessons were also a focus of this interview, although it is difficult to be confident about the representativeness of the teacher's teaching strategies during the class observed. Teachers were asked about a specific activity (e.g., exam review) or social organization of activities (e.g., students working in small groups) that was predominant during the lessons observed in order to gain insight into why such approach was selected. This was intended to help me better understand whether and how the teachers' decisions about these issues implicitly reflected how their conceptions of NOS were brought into their teaching. Teachers were asked how the lessons observed might help their students understand science as a discipline, that is, how scientists think and do their work. Responses to this question were expected to provide further insight into teachers' thinking about NOS and how it may (or may not) have been incorporated into their teaching.

These semi-structured interviews consisted of 12 core questions, with follow-up probes used as needed to explore participants' thinking in relation to the focal NOS constructs further. Although I initially began each interview with the same introductory question and typically progressed through all 12 core questions in the order in which they are listed in the interview protocol, there was some variation when needed. For example, if teachers' responses to one question served as a natural segue to another question elsewhere in the protocol, the researcher moved on to that question and returned subsequently to the questions that were skipped. Furthermore, there were some occasions that required the researcher to ask more in-depth follow-up questions about a response beyond those provided in the protocol. These deviations from the structured protocol were deemed necessary to document teachers' thinking in order to understand their views and decision-making about science education related to NOS more fully. The researcher ensured, however, that all questions in the protocol were posed to participants before concluding the interview.

Each instructional interview was conducted face-to-face with the researcher and lasted approximately 45 minutes to one hour. The interviews were video-recorded to accommodate visualization of any classroom materials the teachers brought with them to the interview, especially because they were asked in advance to select and bring a classroom activity for discussion with the interviewer. Recordings were also made to facilitate later transcription of each interview.

Phase II: Within-program activity. In order to evaluate teachers' NOS understanding prior to and following their research, as well as to document the types of activities in which teachers were engaged during their research thoroughly, several measures were included in Phase II of the study. These included the following: *Pre-research NOS Questionnaire*s, *Pre-research NOS Interviews*, *Daily Activity Logs*, *Weekly Reflections*, *Bi-weekly Activity Interviews*, *Bi-weekly Laboratory Visits*, *Post-research NOS Questionnaire*s, and *Post-research NOS Interview*s. While some of these measures were designed to be major sources of data for answering the research questions, others were included as a means of data verification.

***Pre-research NOS questionnaire*s.** This measure consisted of two parts: a demographics/background portion and questions designed to assess teachers' NOS understanding (see Appendix B). After receiving permission to do so from participants, both the demographics and NOS portions of this questionnaire were sent via e-mail to ensure that teachers were not excluded from introductory RET activities or required to stay later in the day than other RET program participants. Teachers were asked to complete the document at their own pace and return it to the researcher. The following instructions were provided:

> I am asking that you complete the attached questionnaire (either on the computer or printed out and completed by hand). Should you choose to complete it on the computer, please feel free to just e-mail the completed document back to me. Otherwise, I can collect them from you when I see you. The first part of the questionnaire consists of some questions about your own background, while the second asks about your views on science. Please know that there are no right or wrong answers to these questions; I simply want to understand what you think about the questions provided. I therefore ask that you rely only on your own thinking when answering the questions and that you not consult any other resources while responding. You will notice that there are boxes to be checked in responding to some questions and/or shaded areas following more open-ended questions. Should you choose to complete the document on the computer, you simply have to double-click on the check boxes and then change the default value to "checked" when appropriate. For the open-ended questions, just type directly in the shaded area, which will allow you to write as much as you choose for your response. Please take your time answering the questions and feel free to write as much as you would like in response to each. Also, please feel free to let me know if you have any questions.

Participants were asked to return the questionnaire within four days, and all but one participant chose to send the completed document back electronically. The sixth participant filled out the questionnaire by hand and returned it directly to the researcher. Due to the fact that these documents were not completed in view of the researcher, it is unknown how long it took for participants to complete them.

The first portion of this measure consisted of a set of questions designed to obtain information about each participants' educational, research, and teaching background. Teachers were asked about basic demographic information, their education and professional training, and their teaching experience. For each of these questions, participants checked appropriate boxes reflecting their own background and filled in short answers as needed (e.g., degrees conferred and areas of study). Following these, they were asked free-response questions inquiring about their prior science research experience, other science learning experiences, and their hobbies. While the first of these was intended to assess whether the teachers had previously participated in scientific research, the final two questions were posed to ascertain whether they had participated in any other activities which could be viewed as directly or tangentially related to scientific research, as these experiences may have influenced their NOS understanding prior to participating in the RET program.

The second portion of the questionnaire focused on teachers' conceptions of NOS, thus addressing the first research question. Although several different assessments have been previously developed to measure individual's NOS understanding, the one used here was determined to most closely link to the NOS framework used throughout this study. The Views of Nature of Science Form C (VNOS-C) as described by Lederman, Abd-El-

Khalick, Bell, and Schwartz (2002), was completed by participants immediately prior to their participation in the RET summer program (see Appendix B). This open-ended questionnaire was validated in a study conducted by Abd-El-Khalick (1998).

The VNOS-C was selected for use in this study in part due to is previously established validity, but, more importantly, the ways in which it addressed several of the focal constructs of interest in this study, especially *Scientific Knowledge (*e.g., questions 3 and 7), *Variability of Methodology* (e.g., questions 2 and 3), *Modeling and Inscribing* (e.g., question 6), and *Historical and Contemporary Context* (e.g., question 9). Although the questions were not designed in relation to my NOS framework and did not address *all* of the focal constructs of the study, they seemed useful for evaluating participants' NOS understanding and serving as a basis for conversation in the follow-up NOS interview. For example, question number two asks participants, "What is an experiment?" Reponses to this question might reveal participants' thinking about the ways in which scientists use *different methods for conducting their research*. In another question, participants are asked to explain whether they believe that science reflects social and cultural values or is universal, and why they think that way. Participants' responses might highlight their thinking related to the focal construct of the *Historical and Contemporary Context* in which scientific research is conducted. Some questions posed in the questionnaire were not relevant to the focal constructs but were included to maintain validity of the instrument.

Pre-research NOS interviews. After receiving participants' *Pre-research NOS Questionnaire*s, I scheduled individual *Pre-research NOS Interviews* with each participant (see Appendix C). These interviews differed from the previously-conducted

Instructional Interviews in that the focus of the *Pre-research NOS Interviews* was strictly on participants' own understanding of NOS and was not in any way connected to their classroom practice.

Before beginning the semi-structured interview, teachers were told that I was going to ask them follow-up questions about the questionnaires that they had completed, as well as other questions related to their views of science. They were also notified that their questionnaires would be available to them, should they need to refresh their memory about how they had previously responded to any questions. I reminded participants that there were no right or wrong answers to the questions posed and encouraged participants to answer questions as completely as possible, even if they were unsure about their response. Interviews lasted approximately one hour and were video-recorded to aid in later transcription in case the participants made any gestural references back to their previously-completed questionnaires during the interview.

In part, the interview consisted of clarification of teachers' responses to the VNOS-C questionnaire, as recommended by Lederman et al. (2002) to ensure the validity of the researchers' interpretations of these responses. This also allowed the researcher to target the focal constructs more closely through follow-up questions based on individual participants' responses. Other interview questions attended to aspects of the researcher's NOS framework that were not addressed in the questionnaire. Some of these questions draw on the work of Ryder, Leach, and Driver (1999) to focus on participants' overall views of science as a discipline and information about their understanding in relation to some of the focal constructs (e.g., responses to question 2 may shed light on teachers' views of *Variation of Methodology* and *Scientific Knowledge)*. Questions developed by the researcher were designed to address other focal constructs that were not adequately covered in the NOS questionnaire. For example, one question asked teachers to explain whether they believed scientists strive more to produce new knowledge, verify existing knowledge, or both. This question was intended to elicit information related to the *Scientific Knowledge* as *generative* focal construct, which was not explicitly addressed elsewhere.

As in the *Instructional Interviews*, the *Pre-research NOS Interviews* were semi-structured. The protocol included a series of 15 core questions and probes, with another question noted directing the interviewer to follow-up on each of the questions to which participants responded in the *Pre-research NOS Questionnaire*s. Although I began each interview by progressing through the series of questions as listed in the protocol, ordering adjustments were made as needed if a participant's response led naturally to another question in the protocol, and follow-up questions were posed as needed, based on issues raised in responses. The researcher ensured that all questions were posed to participants before concluding the interview. The combination of the written *Pre-research NOS Questionnaire*s and *Pre-research NOS Interviews* was designed to provide converging data about participants' understanding of NOS prior to their participation in research.

Daily activity logs. Teachers were asked to complete *Daily Activity Logs* (see Appendix D) to document the types of research activities in which they participated throughout the research portion of the RET program, as well as the individuals with whom they interacted in completing these activities. I sent a blank log template consisting of several open-ended questions via e-mail to all participants, who were asked to complete the activity logs throughout each day in the RET program in as much detail as possible. Teachers were instructed to copy and paste the log as often as needed each day to record their research activities and to do so whenever they moved from one research task to another. When asked about how often to record such changes in activity, I instructed participants to begin a new log segment any time a new type of activity began and/or the people with whom they worked changed.

Participants were then asked to provide either a paper or electronic copy of their log to me at the end of each day or week, depending on what format and timing was most convenient. One teacher, T3, asked if it would be acceptable to provide copies of his lab notebook, as it documented his daily activity in detail and because he was experiencing difficulty with computer access during his time in lab. I approved this request, reiterating a need for thorough documentation of the types of information addressed in the *Daily Activity Logs,* and made this option available to other participants if they so desired. All other participants chose to record their information in their activity logs electronically, with most sending them back to me daily. In a slight deviation from the original *Daily Activity Log* format, T1 typically copied information from his lab notebook into each log, but still addressed the questions posed in the original log format.

As noted previously, the purpose of these *Daily Activity* Logs was to identify more specifically the kinds of activities and interactions that had potential for influencing teachers' conceptions of science. I anticipated that there would be variation in participants' activities due to the nature of their research projects and the lab environments in which they worked, which would be made visible through these detailed records. In addition, teachers were asked about the individuals with whom they interacted for each activity and in what capacity in order to document the extent and organization of these interactions, as they may play a role in changing understanding of the *Intellectual Interdependence* in the scientific community of practice. These logs were thus intended to provide insight into whether any patterns were evident in aspects of or activities within teachers' research experiences that suggest that they may help promote changes in teachers' NOS understanding, therefore addressing the second research question.

Weekly reflections. In addition to providing logs detailing their daily activities, teachers were asked to complete *Weekly Reflections* at the conclusion of each week during their research placement (see Appendix E). Upon review by the RET Program Director, these reflections were incorporated as part of the RET program commitments, and were therefore posted on an interactive website maintained by two participants in the Research Experiences for Undergraduates program (REU's) who worked with the RET program during the study. It was through this website that all RET participants generated their *Weekly Reflections*, which consisted of responses to several open-ended questions about what they learned during the week (both in general and about science as a discipline), as well as whether what they learned would be useful for helping their students understand science as a discipline and, if so, how this might be incorporated into their instruction.

During the introductory period of the RET program, teachers were instructed to respond to the reflection questions at the end of each week and submit them through the website. The site consisted of textboxes in which teachers would record their names and dates of the reflection. The prompts listed in Appendix E were then presented, with textboxes following each question in which the teachers recorded their responses. Textboxes were all expandable so that teachers could write as much as they wished in response to each prompt. No further instructions were provided on the *Weekly Reflection* website. These responses were automatically sent to the REU's upon online submission, and those submitted by study participants were forwarded on to the researcher electronically.

The purpose of these reflections was twofold. In part, these questions were designed to address the first two research questions by tracking any ongoing changes in participants' understanding of NOS and what types of experiences they thought might contribute to such understanding. Questions one and two of the *Weekly Reflections* were therefore included to aid participants' recall of specific research activities in which they participated that week, which then led to inquiring about the relation between their research activities and their NOS understanding. The reflections were also intended to document teachers' thinking about how they may link their ongoing research experiences to their classroom instruction to communicate ideas about science as a discipline to their students. By documenting participants' thoughts about these connections between research and the classroom throughout their lab placements, I hoped to gain insight into the impact of considering such links immediately after completing different research activities, rather than relying solely on the delayed ideas evident in post-program *Instructional Observations* and *Instructional Interviews*, thus further addressing the third research question.

This measure, along with the *Daily Activity Logs*, was included to permit examination of the similarities and differences in each participant's individual research experience and exploration of whether aspects of their experiences (e.g., participation in lab meetings, collaboration with other researchers in the lab) may have helped in making particular aspects of NOS (e.g., the *Intellectual Interdependence* and the *Generative* nature of *Scientific Knowledge*) more salient to these participants.

Bi-weekly activity interviews. This measure (see Appendix F), as well as the *Bi-weekly Laboratory Visits* (measure number six, to follow), was included in the study primarily as a means to verify of the information contained in teachers' *Daily Activity Logs* and reported in their *Weekly Reflections.* Rather than rely strictly on written, self-report measures, the *Bi-weekly Activity Interviews* (and *Bi-weekly Laboratory Visits*) were designed to elicit further information about participants' ongoing research activities through follow-up interviews and laboratory site visits.

The *Bi-weekly Activity Interviews* were conducted in or near the lab space in which each participant worked during their research placement and were scheduled at the teachers' convenience at the end of the first and third week of their lab placement. A final interview also occurred at the beginning of the fifth week of the research placement, as the teachers only spent the first few days of this week in the lab concluding their work. During these semi-structured interviews, teachers were asked to respond as completely as possible to each question posed and were assured that there were not any right or wrong answers. Teachers' *Daily Activity Logs* and *Weekly Reflections* were available on-hand so that I could ask for further explanation or clarification about their contents if needed, such as verification of the positions and roles of the individuals with whom they interacted during their research and/or more detailed descriptions of what the teachers were physically doing at any given point during their research placement. All questions included in the interview protocol, as well as related probes, were asked of each participant, with deviations from the protocol occurring when issues raised during the interview warranted further exploration. All *Bi-weekly Activity Interviews* were video-recorded in case any gestural references were made to participants' *Daily Activity Logs* or *Weekly Reflections* during the interview sessions. Each interview lasted approximately 15-30 minutes.

As noted previously, *Bi-weekly Activity Interviews* were intended largely to help verify the information that participants reported in their *Daily Activity Logs* and *Weekly Reflections*, hence the time allotted for clarification of any material contained within these documents. Additionally, questions one through three were included to help the researcher get a more complete picture of teachers' views of the types of activities that typically took place in the lab and people's roles in them and the overall goals of their individual research project, as well as to determine how the participants perceive their projects as fitting within the larger research aims of the labs in which they worked. The final question, like that of the *Weekly Reflections*, was included to track teachers' thinking about how their work in the lab might be incorporated into their classroom instruction to help students understand science as a discipline.

Bi-weekly laboratory visits. Along with the aforementioned *Bi-weekly Activity Interviews*, the *Bi-weekly Laboratory Visits* were included in the study to provide verification of the types of activities in which the teachers participated during their research placement beyond that reported in their *Daily Activity Logs* and *Weekly Reflections*. During the weeks that alternated with the bi-weekly reflective interviews (that is, weeks two and four of their research placements), I observed participants as they worked in their labs in order to obtain a better understanding of the settings in which they worked and their day-to-day activity. These observations were scheduled at the teachers' convenience during times that they were conducting work typical of their research experience and during which the researcher was permitted to be present. Due to scheduling constraints, observations of T3 were delayed and therefore fell on weeks four and five of his research placement. All visits lasted approximately one hour, and field notes were generated by the researcher during each visit. When possible, photographs were taken of teachers as they completed their work to document their activity for future reference by the researcher.

Additionally, to document participants' experiences while in the lab, other data sources were collected as appropriate per their relevance and availability. These included copies of any background material (e.g., research papers, research protocols) read by the teachers or any written products generated as part of their participation in research. Participants were asked to send any documents to the researcher electronically. Furthermore, observations of activities in which the participating teachers engaged (e.g., lab meetings) and/or any presentations made by participating teachers during the program were made when possible. Such documents and events were reviewed to determine the variation in the types of research preparation, conclusion, or reporting required of each teacher. These data were intended to be useful for consideration of how the materials or activities may have influenced their conceptions of NOS based on the nature and content of each and prove useful for data triangulation and analysis.

Post-research NOS questionnaire. Upon completion of the research portion of the RET program, participants were asked to complete a *Post-research NOS Questionnaire* (see Appendix B). This open-ended questionnaire was identical in form and content to the *Pre-research NOS Questionnaire*, without the demographic/background information questions. Once again these questionnaires were distributed electronically. The following instructions were provided:

> As I mentioned, I am sending you a follow-up survey that I am asking you to complete and return to me via e-mail. Please be sure to read and respond to all parts of each of the ten questions (e.g., those that have sub-questions and/or ask for examples). Again, there are no correct or incorrect responses- this is simply for me to learn more about your thinking. Although these questions are familiar to you, I ask that you PLEASE not refer back to the responses that you sent me prior to your participation in the RET program. I also ask that you complete these surveys on your own, without outside input. It is very important for my study that I see what you are thinking now that you have come to the end of your research experience without any reference back to your prior thinking, regardless of whether or not your opinions on the questions have changed.

Participants were again asked to return the questionnaire within four days, and all participants submitted their questionnaires via e-mail. Due to the length of time provided to teachers for completion of the document, as well as the fact that they were completed off-site, the average length of time for completion is unknown.

Post-research NOS interview. During the final days of the RET program, after receiving all *Post-research NOS Questionnaires*, the researcher conducted individual *Post-research NOS Interviews* (see Appendix C) with each participant. Like the *Pre-research NOS Interviews*, these interviews were semi-structured to allow flexibility in the ordering of questions asked and follow-up to any questions raised in participants' responses. Again, participants were informed that the researcher was not seeking particular correct or incorrect responses and were encouraged to answer all questions to the best of their ability, regardless of their certainty about any given issue. These interviews ranged in length from approximately 30 minutes to an hour, depending on the length of each participant's responses.

The content of these interviews was very similar to those of the *Pre-research NOS Interviews* and was designed to address the same focal constructs, with the exception of two questions that were removed and three that were added to the protocol. Questions that were removed were those that asked participants to make predictions about their upcoming research experiences, while those that were added asked them to reflect on their research experiences. Furthermore, one of these reflection questions asked teachers about potential connections between their research experience and their classroom instruction in order to obtain their thoughts on this issue immediately following the conclusion of their research, while it was still fresh in their minds and removed from the classroom. The intent was to enable some comparison of their thinking at that point in time with what the researcher later observed in their classrooms.

Both the *Pre-* and *Post-research NOS Questionnaires* and the *Pre-* and *Post-research NOS Interviews* were designed to document teachers' NOS understanding prior to and following participation in scientific research. Consequently, pre/post comparisons of the data gathered using these measures may make changes in participants' conceptualizations of NOS visible. Any changes that did occur in their understanding is most likely attributable to their participation in the RET summer program, particularly the research portion of the program, as they were not participating in any concurrent professional development.

Phase III: Post-program classroom instruction. The measures used during this portion of the study permit comparison of teachers' classroom instruction and views on science education related to NOS after their participation in the RET program to their instruction and views prior to the program (as determined by the measures used in *Phase I: Pre-program classroom instruction)*. These measures sought to determine whether and to what extent changes in NOS understanding as a result of their participation in scientific research influenced their classroom instruction. In order to ensure comparability with the data collected through the Phase I measures, Phase III of the study consisted of nearly-identical measures.

Instructional observations**.** Observations of post-program instruction were conducted in the same manner as pre-program instructional observations. The same procedure was followed for recording data (video, field notes) during individual class periods. The number and nature of these observations differed from pre-program observations, however. The researcher observed five different lessons taught by each teacher, scheduled throughout the school year. The purpose was to obtain a reasonable sample of classroom instruction for each participant. Again, the lessons were selected by the teacher, who was asked to select lessons believed to help their students understand science as a discipline.

In addition, I conducted no fewer than three and no more than five observations of lessons taught as part of the research-based curriculum unit designed by each teacher as part of the RET program. These lessons were of interest because it was felt that they would provide the "best case" for reflecting the teacher's changed views of NOS (if, indeed, they had changed). This belief was based on the fact that the RET curriculum lessons were developed by teachers during the summer program explicitly to reflect a student-appropriate version of the content and nature of the scientific work they had been conducting. Including the five regular instruction lessons and the three to five RET research-based lessons, each teacher was observed on eight to ten occasions in total. During all lessons observed, the researcher documented the instructional strategies employed, the social organization of these activities, and the nature of the content communicated.

Analysis compared instruction before and after the summer RET program to identify any changes in NOS-related instruction, thus addressing the third research question. Moreover, regular post-program instruction and research-based curriculum post-program instruction were compared to ascertain whether instructional changes (if any) were restricted to the curricular units developed during the summer program or, alternatively, occurred on a wider basis. Although different content was being taught during the observations being compared, the focus for analysis is on an issue general across the content areas, namely, the ways that teachers typically organize instruction and how this might explicitly and/or implicitly reflect their understanding of NOS.

Instructional interviews. As with the aforementioned *Instructional Observations*, post-program *Instructional Interviews* (see Appendix A) were conducted with each participant once all the post-program observations were complete. Post-program *Instructional Interviews* were conducted one-on-one with the researcher and lasted approximately 40 minutes to an hour. These interviews were audio-recoded for later transcription, as the teachers were not asked to bring any material products to share.

All questions from the pre-program *Instructional Interview* were included in the post-program interview; however, two questions were modified and two questions were added (questions 5, 9, 13, and 14 in Appendix A). These modifications were designed primarily to highlight teachers' thinking about how specific activities that they employed in their instruction may or may not help students understand NOS, how their regular and research-based curriculum instruction differed, and how their participation in research may have impacted their instructional decision-making. The final question of the post-program *Instructional Interview* was added to ascertain whether the teachers had remained in contact with their research mentors during the school year and, if so, whether this contact further influenced their instructional design and decision-making.

As during the pre-program *Instructional Interviews*, I followed the question order of the interview protocol, unless diverted to another question based on a participant's response. Once questions 1-13 were addressed, I posed the final question, number 14, as a concluding question in which participants could share any closing thoughts about their RET experience.

On two occasions (T1 and T6), the teacher had to conclude the post-program *Instructional Interview* early due to participants' time commitments, and neither was able to reschedule a time to complete the interview. T1's interview concluded before I could ask two follow-up questions based on issues he had raised in his interview responses, and before I could pose the final interview question (number 14). For T6, there was insufficient time to ask a follow-up to question 11and the final three questions in the interview (numbers 12 through 14). In both instances, the teacher agreed that I could send any remaining questions to them via e-mail. Once initial responses to these questions were received by the researcher, any necessary follow-up questions were also communicated and answered electronically. The final question of the interview (number 14) was developed after the completion of interviews with T2 and T3. This question was also sent to these participants via e-mail and responses were received in the same format. While most of the measures used to collect data from each of the six teachers were identical, there was some variation in the manner by or extent to which each measure was deployed. These differences are noted in Table 4 below.

Table 4

Differences in Measures Deployed, by Participant

	Data Sources			
ID	**Pre/Post Classroom Observations: Video**	**Pre-program: Number of Classroom Observations**	**Post-program: Number of Classroom Observations- Research-based Curriculum**	**Daily Activity Logs**
T1	Yes- all	3	5	Yes
T2	Yes- all	2	5	Yes
T3	Yes- all	2	3	No; provided copies of lab notebook
T4	Not available	2	5	Yes
T5	Not available	2	3	Yes
T6	Not available	2	3	Yes

As noted previously, all measures used were designed to address the constructs selected as the focus of this study. Table 5 below indicates which focal constructs and construct subcategories were targeted by each of the study measures.

Table 5

Focal Constructs and Subcategories Targeted by Study Measures

Data Sources	**Focal Constructs**					
	Intellectual Interdependence: ***Intra- and Interdisciplinary exchange***			**Variability of Methodology**		
	Research experiences relevant to this aspect of NOS	**Teachers' thinking about this aspect of NOS**	**Teachers' instruction related to this aspect of NOS**	**Research experiences relevant to this aspect of NOS**	**Teachers' thinking about this aspect of NOS**	**Teachers' instruction related to this aspect of NOS**
Pre/Post Instructional Observations			X			X
Pre/Post Instructional Interviews			X			X
Pre/Post NOS Questionnaires and Interviews	Post interview only	X		Post interview only	X	
Daily Activity Logs	X			X		
Weekly Reflections	X	X	X	X	X	X
Bi-weekly Reflective Interviews	X	X	X	X	X	X
Bi-weekly Lab Visits	X			X		
Other Data Sources	Lab-related materials		Lesson-related materials	Lab-related materials		Lesson-related materials

Table 5, continued

Data Sources	**Focal Constructs**					
	Scientific Knowledge: ***Generative; Co-constructed***			**Modeling and inscribing:** ***Types of Models***		
	Research experiences relevant to this aspect of NOS	**Teachers' thinking about this aspect of NOS**	**Teachers' instruction related to this aspect of NOS**	**Research experiences relevant to this aspect of NOS**	**Teachers' thinking about this aspect of NOS**	**Teachers' instruction related to this aspect of NOS**
Pre/Post Instructional Observations			X			X
Pre/Post Instructional Interviews			X			X
Pre/Post NOS Questionnaires and Interviews	Post interview only	X		Post interview only	X	
Daily Activity Logs	X			X		
Weekly Reflections	X	X	X	X	X	X
Bi-weekly Reflective Interviews	X	X	X	X	X	X
Bi-weekly Lab Visits	X			X		
Other Data Sources	Lab-related materials		Lesson-related materials	Lab-related materials		Lesson-related materials

Table 5, continued

Data Sources	**Focal Constructs**		
	Historical & Contemporary Context: ***Beliefs and Values***		
	Research experiences relevant to this aspect of NOS	**Teachers' thinking about this aspect of NOS**	**Teachers' instruction related to this aspect of NOS**
Pre/Post Instructional Observations			X
Pre/Post Instructional Interviews			X
Pre/Post NOS Questionnaires and Interviews	Post interview only	X	
Daily Activity Logs	X		
Weekly Reflections	X	X	X
Bi-weekly Reflective Interviews	X	X	X
Bi-weekly Lab Visits	X		
Other Data Sources	Lab-related materials		Lesson-related materials

Data Analysis

The research questions were answered through analysis of pre-, post-, and within-program data to determine how and to what extent participants' NOS understanding and classroom instruction related to NOS changed as a result of their participation in research.

Data coding. Three coding schemes were used throughout the analysis of the data: (1) NOS Understanding; (2) Teacher Talk about Instruction Related to NOS; and (3) Research Activities and Interactions. For the *NOS Understanding* coding scheme, I first developed an initial set of codes describing differing levels of sophistication of NOS understanding in relation to each of the focal NOS constructs by drawing upon their descriptions in my NOS framework. These codes were then refined and clarified in ways grounded in the data that was collected. The *Teacher Talk about Instruction Related to NOS* coding scheme was also developed in this way. This coding scheme built upon the *NOS Understanding* coding scheme by describing the differing levels of sophistication with which teachers discussed the value of developing and/or how they might help cultivate students' understanding of each of the focal NOS constructs. Consequently, both the *NOS Understanding* and *Teacher Talk about Instruction Related to NOS* coding schemes consisted of descriptions and their corresponding codes for several different levels of understanding in relation to each focal construct. The *Research Activities and Interactions* coding scheme was developed to describe different aspects of teachers' research experiences and for analysis of whether specific types of research experiences might help make certain aspects of NOS more salient for study participants. Descriptions of measure-specific coding procedures and subsequent analyses are described below. The coding schemes employed for each measure, however, are described in the relevant sections of Chapter IV to provide greater accessibility to these descriptions while reviewing study results.

Pre/post-research experience analyses. As noted previously, four measures were designed to explore changes in teachers' thinking and instruction related to NOS as a result of their research experience. These included pre- and post-research experience *NOS Questionnaires*, *NOS Interviews, Instructional Observations*, and *Instructional Interviews*. Descriptions of how the data generated by each of these measures were coded and analyzed are provided below. The order in which they are presented here reflects the order in which they were analyzed, as the *Instructional Observations* and *Interviews* were designed to capture the extent to which participants' conceptions of NOS (as evidenced in the *NOS Questionnaires* and *Interviews*) were reflected in their thinking about and enactment of classroom instruction.

NOS questionnaires and interviews. Pre/post data generated through participants' completion of the *NOS Questionnaire* and *NOS Interview* were analyzed in order to identify to what extent change in their NOS understanding occurred as a result of their participation in research. Some guidelines currently exist for analysis of the *NOS Questionnaire* used, the VNOS-C, as determined by the instrument's developers. This entails categorizing participants' responses as revealing more or less naïve ideas about NOS (Lederman et al., 2002). Although the questions included in the VNOS-C are designed to target specific aspects of NOS, it is suggested that the researcher analyze a participant's entire set of responses independent of the questions posed. This is recommended because, although VNOS-C questions were designed to elicit thinking of certain aspects of NOS, it is the entire set of responses that is intended to provide a picture of NOS understanding (F. Abd- El-Khalick, personal communication, August 4, 2010). This, along with the fact that this questionnaire was not designed to align with my own NOS framework and the expansion upon participants' written responses provided through the *NOS Interview*, led me to aggregate data collected through both the *NOS Questionnaire* and *Interview* for each participant. Coding and analyses of data from these two measures therefore took place in tandem using the same coding scheme (described in detail in Chapter IV as previously noted) for both measures.

In order to characterize participants' understanding of NOS as communicated through their *NOS Questionnaire* and *Interview* responses, *NOS Questionnaire* responses, as well as transcripts of *NOS Interviews*, were analyzed at the idea-unit level. For this study, an idea unit consisted of a response or portion of a response (e.g., a sentence or two) that explained the teachers' thinking about a specific construct at a particular level of understanding. Idea units varied in length depending on when the emphasis of participants' responses shifted with respect to focal constructs. Therefore, if a participant addressed more than one construct in their response to a single question, portions of responses were coded to the most suitable level of the appropriate construct. Idea units reflective of more than one level of understanding were coded to the level that most closely described the thoughts being communicated. If this was evenly distributed across two levels, the idea unit was assigned the higher-level code. Only statements relevant to the focal constructs were coded for analysis.

Following coding of all idea units, pre/post comparisons were made to determine to what extent participants' talk about the focal constructs changed during their *NOS Questionnaires* and *Interviews*. For each participant, the proportion of idea units receiving different level codes *within* each construct (that is, what level of sophistication of understanding was reflected whenever the participant said or wrote something related to a particular construct) was compared across pre/post measures for each participant. These comparisons were conducted to highlight pre/post shifts in the sophistication of participants' understanding in relation to each of the focal constructs as evidenced by the idea units communicated through their *NOS Questionnaires* and *Interviews*.

Given the small sample size of my study, these proportions were used as a means for describing and making broader qualitative comparisons of how participants' thinking about NOS may (or may not) have changed after participating in research. This was intended to help me to characterize them in terms of their shifting understandings and generate both within-case pre/post-program comparisons and cross-case comparisons of shifts in NOS understanding. Results of these analyses are described in Chapter IV.

Instructional observations. These observations were designed to capture the ways in which participants enacted instruction related to NOS and communicated ideas about NOS to their students (both explicitly and implicitly) prior to and following their participation in scientific research. Field notes generated for *Instructional Observations* were used to explore how ideas about NOS may have been communicated to students explicitly and/or implicitly though teachers' different approaches to instruction. This allowed qualitative description of the typical instruction enacted in each participant's classroom during the observation periods. This was intended to provide a broader picture of the instructional strategies used by each participant to look for overall pre/post-program changes in their teaching.

It is important to note that, for observations conducted in teachers' classrooms following their participation in the RET program, comparisons were also made between the teachers' regular instruction and their instruction during their research experience-based curriculum module. Further analysis of post-program observations therefore sought to compare teachers' regular and module-based instruction to investigate whether the development of research experience-based curriculum provided more fertile ground for communicating conceptions of NOS to students differently than during their regular instruction.

The analyses described above allowed me to make both within- and cross-case qualitative pre/post comparisons of the means by which teachers explicitly and/or implicitly communicated ideas about NOS through their instruction. Results from all of these analyses can be found in Chapter IV.

Instructional interviews. Teachers participated in *Instructional Interviews* to determine how they thought about NOS-related instruction prior to and following their research experience. In order to do so, pre- and post-program interviews were coded in order to capture how each participant talked about NOS instruction overall, as well as instructional strategies they felt more closely reflect accurate conceptions of NOS. Transcripts were used for coding of all *Instructional Interviews*. Coding procedures again occurred at the idea-unit level in the same manner described for the coding of *NOS Interviews* and *Questionnaires*. Pre/post comparisons of the proportional data generated through analyses of *Instructional Interviews* were made in order to explore changes in the ways in which teachers talked about their instruction related to NOS. Descriptions of results from these analyses are located in Chapter IV.

Within-program research experience analyses. The remaining study measures, including the *Daily Activity Logs*, *Weekly Reflections*, *Bi-weekly Activity Interviews*, and *Bi-weekly Lab Visits*, were designed to document the activities in which teachers participated while working on their research projects. As mentioned previously, the *Bi-weekly Activity Interviews* and *Bi-weekly Lab Visits* were intended to verify information contained in participants' *Daily Activity Logs.* While the *Weekly Reflections* were designed to track ongoing changes in participants' understanding of NOS and what types of experiences they thought might contribute to such understanding, as well as document teachers' thinking about how they may link their ongoing research experiences to their classroom instruction to communicate ideas about science as a discipline to their students, review of participants' responses revealed that responses were too sparse to serve as a stand-alone data source. They were therefore used as another means for verification of information contained within participants' *Daily Activity Logs*.

A set of categories was developed in order to classify and differentiate between teachers' individual research experiences. These categories focused on describing the overall role of each teacher's project in relation to the lab's ongoing research agenda, the teacher's role in their project, the individuals with whom they interacted during these activities and the relative frequency of these interactions, and the teachers' involvement in different types of lab meetings (if any). Using data collected through participants' *Daily Activity Logs*, *Weekly Reflections*, *Bi-Weekly Activity Interviews*, and *Bi-Weekly Lab Visits* in relation to each of these categories, individual profiles of each teacher's distinct research experience were generated. These data were then compared to any changes noted in individuals' NOS understanding in order to determine whether certain types of research experiences may have helped make particular aspects of NOS more (or less) salient to participants. The results of these investigations are reported in Chapter IV.

CHAPTER IV

RESEARCH EXPERIENCES, NOS, AND CLASSROOM INSTRUCTION: INTERACTIONS AND DISCREPANCIES

In order to explore the outcomes of this study most appropriately, I will begin by first describing participants' research experiences, as these experiences may provide insights into the enterprise of science that underlie any changes in NOS understanding. This will then lead into discussion of the changes (or lack thereof) in teachers' NOS understanding that occurred as a result of these varying experiences. Finally, I explore whether any changes were evident in participants' instruction that reflected these shifts in their NOS understanding.

Participants' Research Experiences

Although the program in which study participants took part was formally titled Research Experiences for Teachers (RET) in Engineering, and they were therefore placed within engineering-based labs, their experiences with research varied widely. Not only did the departmental affiliations of the labs differ, but even for those teachers who worked in labs within the same department, their specific research focused on dissimilar aspects of a seemingly related topic. Table 6 highlights these differences by providing a summary of the school and departmental affiliations of the labs in which each participant worked, the overall focus of the research in the lab as described by the study participant, and a brief description of the study participant's project while working in the lab.

Table 6

Overview of Participants' Research Placements

Teacher	**Overall Lab Context**	**Departmental Lab Context**	**Lab Research Focus**	**Teacher's Project Focus**
T1	School of Engineering	Electrical Engineering and Computer Science	Medical image processing for real-time use in surgical procedures	Computer modeling of electric fields in the brain during stimulation by implanted electrodes
T2	School of Engineering	Biomedical Engineering	Medical imaging for evaluation of human bone strength	Preparation of bone samples for mechanical and imaging testing
T3	Institute of Imaging Science	Radiology and Radiological Sciences	Medical imaging for evaluation of cancer treatment efficacy	Culturing multiple cancer cell lines; protein analysis of cultured cell lines
T4	School of Engineering	Mechanical Engineering	Medical applications of mechatronics	Redesign and development of haptic paddle device used in graduate and undergraduate courses
T5	School of Engineering	Chemical and Biomolecular Engineering	Development of polymer films with water and oil resistant properties	Creation and testing of polymer samples
T6	School of Engineering	Chemical and Biomolecular Engineering	Design and development of polymer composites as potential substitutes for human bone	Culturing bone cells; preparation and testing of composites using cultured cells

In order to illustrate the differences in study participants' research placements beyond those summarized in Table 6, I next provide narrative descriptions of each teacher's research experience. Several key distinctions among these research experiences are then compared across participants in relation to the focal NOS constructs to highlight how different aspects of a teacher research experience may help make certain aspects of NOS more or less salient.

T1's Research Experience: Medical Applications of Computer Modeling

As noted in Table 6, T1's project during the RET program was focused on computer modeling of electric fields in the brain for use by neurosurgeons during deep brain stimulation surgery (an intervention for neurological disorders such as Parkinson's disease). T1 therefore spent the majority of his time in the lab working on computer programming intended to improve the effectiveness of these models. This took place in a room containing several computers on which T1 and other project personnel worked; however, most of T1's work was completed independently of the other individuals working in this room. He was allowed a greater degree of autonomy than other teachers participating in this study of research experiences, as he did not have an individual with whom he worked for the entirety of each day of his research experience. Instead, T1 met with his PI and other research faculty multiple times each week in order to talk about his progress, discuss any difficulties that arose for T1 as he completed his programming, and confer about both the practical applications of his work and future directions for his project. He continually expressed the value of these meetings in his *Daily Activity Logs*, *Weekly Reflections,* and *Bi-Weekly Activity Interviews*, and at one point wrote the following:

> Working with [one university researcher] was…awesome - he really takes the time to dig deep… [He] & I worked together on Wed PM & Thurs AM [*sic*]. He also worked on the proof at home and emailed [MATLAB] equations to me. [T1's PI] also gives his time very freely even though it is crunch time on a big grant. He sees through problems really quickly or in making me explain myself helps me to see a path to solution of a problem. (T1 Weekly Reflection, RET Week #4)

These recurring, one-on-one meetings with those overseeing T1's work appeared to supplant the need for whole-group research meetings, as no such meetings were held during his time in the lab. Instead, individuals in the lab worked fairly independently but still toward the converging goal of developing the most effective means for compiling and manipulating medical images for use by neurosurgeons during deep brain stimulation surgeries (T1 Bi-Weekly Activity Interviews #1 and #2).

Approximately half way through the RET program, T1 was permitted observe a deep brain stimulation surgery, thereby providing him the opportunity to witness directly the potential impact of his work in a clinical setting. In a *Bi-weekly Activity Interview* following his observation of the surgery, T1 explained that his experience enabled him to comprehend the existing surgical procedures and how the work he was doing would ultimately help expedite and improve the efficacy of the process. This type of experience was unique to T1, as no other study participant was presented with opportunities to make such concrete connections to the real-world applications of their work.

T2’s Research Experience: Novel Methods for Evaluating Bone Strength

Most of T2’s research experience took place in a small room used for the cutting and preparation of samples of human bone for mechanical testing and medical imaging. Although the ultimate intent of her project was to participate in data collection to assess bone strength through this testing and imaging, that point was not reached during T2’s time in the lab, as the apparatus for cutting the bone first had to be developed. T2 worked closely with one graduate student throughout this entire process, observing and eventually assisting with the bone preparation process. The research group of which the graduate student was a part had a centralized room in which they could work, but T2 spent very little time in this space and therefore had little interaction with others who were working on related projects under her mentor PI. Instead, most of her time was spent in the bone-cutting room, which was located in a different part of the building than the main lab space. Despite this, T2 had some opportunities to interact with other researchers throughout her research experience, such as when she spent a portion of a day shadowing a worker in the bone center whom T2 understood to work with both her PI and another PI at the university (T2 Daily Activity Log #10 and Bi-Weekly Activity Interview #3). Contact with her mentor PI primarily consisted of occasions in which he visited the room in which T2 and the graduate student worked in order to monitor their progress on the project. As she explained:

> [T2’s PI] kind of steps in, you know, periodically just to make sure that everything’s going okay and to see if we have any questions about what we need to do...then, you know, he’ll come back and, or he’ll email and say, you know,

> let’s try it this way, or let’s do it this way. (0:02:45, T2 Bi-Weekly Activity Interview #3)

She did, however, have some opportunities to work alongside her PI when he filled in for the graduate student with whom she worked, preparing bone samples with T2 when the graduate student had other commitments (T2 Bi-Weekly Activity Interview #2). As with T1, lab meetings designed to bring together all individuals working on related projects under the mentor PI did not take place during T2’s time in her lab.

In addition to her daily work in the lab, T2 had the opportunity to attend a two-day conference about medical imaging that was held on-site at the university, as well as a seminar conducted within the imaging department. T2 did not actively participate in these meetings, but she was able to listen to presentations made by researchers in the field. Therefore, although she did not attend any sort of lab meeting directly related to her own work, T2 was able to experience settings in which researchers came together to share their work. Unfortunately, the material addressed in these settings, particularly the imaging conference, was beyond the scope of T2’s knowledge. As she stated in one weekly reflection, “I found the conference interesting; however, for the most part I was completely lost” (T2 Weekly Reflection, RET Week #1). This lack of understanding of conference content may have impacted her ability to grasp fully the types of intellectual exchange that was likely occurring throughout these events.

T3’s Research Experience: Evaluation of Cancer Treatment Efficacy

T3’s research experience took place in a setting in which several researchers with differing areas of expertise worked within common lab space on individual parts of the lab's larger research goals. These goals focused on using imaging for evaluation of the efficacy of different treatments for cancer. As T3 explained in his final *Bi-weekly Activity Interview*, some individuals' work focused more on cellular and molecular aspects of the project (e.g., T3's work with cell culture and protein extraction), while others worked on chemistry-based pieces (although T3 could not clearly explain what this entailed). He worked closely with one graduate student to explore differences in proteins of certain lines of cancer cells and, in doing so, had the opportunity to learn about and ultimately carry out an array of lab techniques.

Despite working in the same physical space as other researchers, T3 described little interaction that took place among them on a daily basis. T3 did have the opportunity, however, to learn about their work while attending weekly lab meetings. During these meetings, led by T3's PI, each member of the research team reported on their progress on their projects. T3 explained that these meetings "exposed [him to] how the different areas of the lab are working together to achieve the goals in the grant projects currently underway. The chemistry and molecular biology departments require each others [*sic*]expertise to reach new breakthroughs" (T3 Weekly Reflection, RET Week #3). T3 also had the opportunity to present his own work during one of these meetings at the end of his time in the lab. For this experience, T3 used PowerPoint to prepare and present an overview of the work that he and the graduate student completed during his time in the lab. T3's PI interjected questions and comments intermittently throughout the presentation. T3 responded to the best of his ability, drawing upon the graduate student with whom he worked as needed (T3 Bi-Weekly Lab Visit #2).

T3 had the opportunity to attend the same imaging conference as T2 during his time in the lab. He stated in *Bi-Weekly Activity Interview* #1, which took place following this experience, that his knowledge base was not great enough to comprehend all that was presented. In this interview, however, he also explained his developing understanding of how imaging can be used in research settings and commented on the fact that individuals working on vastly different types of projects may still rely on the same types of technology to conduct their research. T3 also described the benefit of having been exposed to all of the language and terminology employed by researchers in the imaging field both in *Bi-Weekly Activity Interview* #1 and *Weekly Reflection* #1. Therefore, despite his inability to comprehend all that was presented during the conference, T3 was able to glean some understanding of certain aspects of the field and of research as a whole.

T4's Research Experience: Device Design for Teaching of Dynamics

As noted in Table 6, T4's project during his research experience was focused on redesigning a haptic paddle device for use in several university courses to help students understand "system dynamics and about…controller interface and force feedback" (0:03:13, T4 Bi-Weekly Activity Interview #2). Although related to the lab's research in mechatronics, T4's individual project was not designed to help further the overall research goals of the lab in which he worked. T4 worked on this design project fairly independently under the guidance of a graduate student in the lab. He spent most of his time researching existing, comparable devices, developing plans for the redesign of the device, generating computer-based models for the redesign, revising these plans, writing computer code to control the haptic paddle, and sourcing parts for the device. Ultimately

T4 aimed to build a prototype of the haptic paddle device before the conclusion of his research experience. During this time, even though the lab occupied a centralized room in which most project personnel worked, T4 typically worked in a separate room and checked in regularly with his cooperating graduate student in order to discuss his progress and potential approaches to his redesign process.

Most of T4's interactions with his mentor PI took place during weekly lab meetings, which he was able to attend. He described his first experience in this type of meeting as follows:

> I found it informative about the topic and interesting to see how the group interacted to help improve the design of the project. Professors of many years of experience were learning from the research done by the grad student and the grad student was learning from the experience of the professors. It wasn't about defending or posturing just pure brainstorming and revisions. (T4 Weekly Reflection, RET Week #1)

Later in his research experience, T4 explained that he felt that another of the weekly lab meetings that he attended had been less helpful, as it seemed less productive and was focused on issues unrelated to his own work (T4 Weekly Reflection, RET Week #4). In addition to these formal lab meetings, T4 also had the opportunity to participate in a brainstorming session focused solely on his own project with his mentor PI and some other lab members. He described this session as being useful for generating ideas as he moved forward with his device design (T4 Bi-Weekly Activity Interview #1). Therefore, although most of his daily interactions occurred mainly with a single graduate student, he did have some opportunities to discuss his project with others, as well as learn about the other projects being pursued in the lab as a whole.

T5's Research Experience: Development and Testing of Innovative Polymers

Throughout his research experience, T5's project was focused on testing different types of polymers for their ability to repel both oil and water. This work tied closely to the lab's overall goals of developing polymers that could be used to coat surfaces to make them oil- and water-resistant. Of all study participants, T5 had the most consistent day-to-day activity, as he continuously repeated the same protocol designed to apply the polymers to a surface and test their oil- and water-resistant properties. He completed these procedures independently once he had been trained in the protocol by graduate students working under T5's mentor PI. At times, in addition to his independent lab technician-like work of completing the polymer testing protocols, T5 also assisted the graduate students with their projects when it related to T5's work. This work took place in a lab area that was adjacent to a communal room in which several graduate students worked on their own projects. T5 therefore worked in close proximity to these graduate students and interacted with them regularly, both formally about lab-specific issues but also informally during times that they were not working or were waiting to complete next steps in their research protocols (T5 Bi-Weekly Lab Visit #2).

Given that his work took place in cooperation primarily with graduate students, T5 had few interactions with his mentor PI. In his second *Bi-Weekly Activity Interview*, T5 explained that, instead of regular, whole-group lab meetings, his mentor PI occasionally met with smaller groups of individuals focused on particular aspects of the lab's work. T5 therefore had the opportunity to meet with his PI approximately mid-way through his research experience and again toward the end of this time. In these meetings, T5 and the graduate student with whom he worked most closely provided the PI with updates on the progress of their projects and solicited feedback about how to move forward in their work. Beyond this, T5 did not indicate any other occasions during which he encountered his mentor PI in his Daily Activity Logs, Weekly Reflections, or Bi-Weekly Activity Interviews.

T6's Research Experience: Testing Polymer Composites as Bone Substitute

T6's work during her research experience was focused on culturing cells and testing how well they grew on different types of polymer composites, which was part of a larger project investigating ways in which human bone could be replaced *in vivo*. She worked closely with one particular graduate student throughout this time, first observing his work and then participating in different aspects of the project alongside him and under his guidance. T6's *Daily Activity Logs* reflected a shift in her role more clearly than all other study participants, as she began by describing her role in the day's activities as simply an observer but gradually indicated more hands-on participation over time. For instance, by her third day in the lab, she described her role as "[o]bserver in most of it as well as actually changing out the media and freezing the cells" (T6 Daily Activity Log, Day 3). This then transitioned to descriptions reflecting a more central role, and by the end of her first full week in the lab (Day 7), identified her role as "performer/learner" of the tasks she completed that day. T6 continued to refer to herself in this manner throughout most of the rest of her *Daily Activity Logs* during her research experience.

The daily environment in which T6 worked was the most consistently populated of those observed, as she primarily worked in a large lab space occupied by several researchers working under her mentor PI. T6 described these individuals as being at different phases in their study of the composites on which they worked (T6 Bi-Weekly Activity Interview #2). Despite this environment, T6 had few direct interactions with individuals other than the graduate student with whom she worked. Additionally, few opportunities arose for T6 to speak with her mentor PI beyond her initial introduction to the lab, as formal lab meetings were not held within this group. T6 did, however, have the opportunity to attend a meeting that drew together the researchers working in her lab and those with whom they collaborated in a bone lab. She explained that "[t]here were a lot of things that the engineering students needed guidance on from the biology students. It made me realize how important it is to colaborate [*sic*] in science" (T6 Weekly Reflection, RET Week #4).

Differences in participants' research experiences in relation to NOS. In addition to differences in the labs in which study participants worked as summarized in Table 6 and further explored in the research narratives, these narratives also make evident that notable variation existed in the roles of teachers' projects in relation to the lab's overall research goals, teachers' roles in their projects, the individuals with whom the teachers interacted throughout their research, and their involvement in lab meeting experiences. Table 7 summarizes these aspects of each study participant's research experience. More extended direct comparisons of these differences among participants' experiences follow, along with commentary on the quality of each study participant's NOS experience during their time in the lab as a consequence of such differences.

Table 7

Overview of Participants' Research Activities

Activity Category	**Codes**	**Participant**					
		T1	T2	T3	T4	T5	T6
Overall Role of Project	Part of lab's ongoing research agenda	✓	✓	✓		✓	✓
	Unrelated to lab's ongoing research agenda				✓		
Teacher's Role(s) in Project	Developed own project and methods	✓					
	Developed and followed own methods	✓			✓		
	Independent technician					✓	
	Research assistant		✓	✓		✓	✓
Teacher's Interpersonal Interactions[a]	PI	I	I	I	I	O	O
	Other researchers	C	O	I	O	A/U	O
	Grad student(s)	O	C	C	C	C	C
	Other misc. personnel	O	A/U	I	O	A/U	O
Lab Meeting Experiences	Presented			✓			
	Attended/ participated			Weekly	Weekly		
	Attended meeting or event involving broader set of labs and/or researchers	Observed research-related surgery	Attended Imaging Conference; attended seminar	Attended Imaging Conference	Attended multi-lab meeting		Attended multi-lab meeting

[a] Relative frequency of interactions are indicated using the following scale: *C*(consistent; 3 or more times per week); *I* (intermittent; 1-2 times per week); *O*(occasional; less than once per week); *A/U* (absent/unknown; no interactions indicated).

As can be seen in Table 7, most study participants took on the role of a research assistant while working in their labs, meaning that they worked alongside a researcher, typically a graduate student, assisting them with their work that was selected as the focus for the teachers' summer research. One participant, T5, also functioned essentially as a technician at times, independently repeating an established protocol to test polymers developed in the lab. Only two study participants (i.e., T1 and T4) had enough autonomy to develop their own methods for working on their research projects, yet only the work done by T1 was intended to help advance the overall goals of the lab in which he worked. As noted previously, T4's work was related to his lab's focus on mechatronics, but this redesign was aimed at improving the device for use in a university-level course. Therefore, with respect to the relation of the participant's project to the lab's goals and the role that the study participant took on in working on their project, T1 had the most authentic research experience of the study participants, which may have provided him with greater insight into aspects of NOS related to the products and goals of science than those who were not able to envision the potential impacts of their own work as clearly.

Regardless of study participants' project focus and their role in its completion, all interacted with a range of personnel throughout their research experiences. The relative frequency with which they interacted with these different individuals and the nature of these interactions varied, however. For most study participants (i.e., T2, T4, T5, and T6), the majority of their interactions were with the graduate students with whom they worked, with some exchanges with the PI heading the lab. T2 and T6 continuously worked alongside a graduate student, while T4 and T5 relied upon the graduate students more as a resource as they continued their work independently. Although both T2 and T4 interacted with their PI more frequently than T5 and T6 (whose PIs generally checked in on their lab as a whole), these interactions looked quite different. T2 described a few instances in which she worked with the PI doing the same type of work that she did along with a graduate student during his absence. T4, however, had opportunities to talk through his device redesign process with the PI and interact with him though their weekly lab meetings. T3 also interacted most frequently with graduate students but also came into intermittent contact with the PI, other researchers, and other lab personnel through his attendance in weekly lab meetings and a conference. He also had the unique opportunity to interact with these individuals as a presenter in one of the group's weekly lab meetings. Of all study participants, T1 interacted most frequently with other researchers during his research experience. Throughout his *Daily Activity Logs*, T1 emphasized the ways in which he solicited ongoing feedback and advice from other researchers who collaborated with his PI. He also communicated more directly through one-on-one interactions with his PI about his progress on and next steps in his project than any other program participant. It is important to note that T1 interacted most consistently with these individuals (i.e., his PI and other researchers) rather than graduate students, whereas the reverse was true for all other program participants.

The implications of these differences in interpersonal interactions for the development of NOS understanding are interesting, as one must consider to what extent each participant moved along the trajectory from observer of research practices to participant in them and the potential consequences of such progression. Those who worked closely with graduate students may have had rich opportunities for eventually conducting the same type(s) of work as these graduate students (albeit likely with more supervision) as they progressed from observer to participant, as it is typically the graduate students themselves who are responsible for much of the day-to-day data collection and analysis. Additionally, graduate students may be viewed as less intimidating than a PI, therefore the teachers who worked closely with them may have felt more comfortable interacting with them, which could foster a more collaborative environment for the teacher. Despite this, T1 clearly regularly experienced positive, productive interactions with his PI and other research faculty. While this may also have occurred had other teachers been placed in the lab in which T1 worked, he showed a unique level of interest in and enthusiasm for his work, as well as diligence and dedication to his project (as evidenced by his reports of working on it after having left the lab for the day, as well as on weekends), which likely facilitated his ability to interact effectively with his research mentors. T1's relatively extensive, 32-year teaching experience (in comparison, the next-most experienced teacher had been teaching 8 years at the time of the study) may have facilitated these interactions further, as he not only taught courses most closely linked to the focus of this RET program (i.e., engineering courses), but he also had time and opportunities to participate in professional development programs aimed at advancing his content knowledge (e.g., particle physics) and using university-generated data sets in science curricula. Although these prior experiences did not afford him opportunities to participate in research directly, taken together, they may have contributed to his confidence when interacting with his mentors and bolstered his credibility in the eyes of these mentors.

The varied extent to which study participants engaged in lab meeting experiences is also particularly notable. Participation in such activities may provide participants with insight into the role of collaboration in research, particularly the intra- and interdisciplinary exchange that occurs in such settings and the means by which these collaborations can lead to the co-construction of knowledge. While most of the teachers attended or participated in some type of collaborative meeting or event at some point during their time in their lab, T5 lacked any such experience. Only two study participants, T3 and T4, regularly attended formal lab meetings, and T3 even had the opportunity to present the results of his work during a lab meeting held at the conclusion of his research experience.

Other opportunities for study participants to experience interpersonal interactions that might help them learn about different types of ongoing research may have existed in interactions among RET teachers, whether through informal discussions and/or their weekly group lunches. Informal interactions among participants, like those provided in the regular lunchtime conversations, were not asked about, but none of the teachers spontaneously mentioned that any of these interchanges were important in influencing their ideas about science. Therefore, while these experiences may have fostered group collegiality, they were not viewed by study participants as a means for explicitly helping them understand NOS. This is perhaps not surprising given that this was not a stated goal of the RET program and discussion was, accordingly, not directed purposefully toward NOS.

Clearly, there were vast differences in research experiences, and each teacher’s experience was unique. Certain features may have been more likely to promote sophisticated understanding of the focal NOS constructs than others. For instance, as noted previously, it may have been very important for teachers to be able to contextualize their research with respect to the overall goals of the lab and to see how their work contributed toward these goals, particularly for understanding the generative nature of scientific knowledge. If so, T4 would have been at a disadvantage, as he struggled to see how his project might fit within the lab's work overall. It is worth noting that the work done by T4 during his research experience was eventually taken up as a line of research in the lab in which he worked (S. Klein-Gardner, personal communication, November 20, 2012). It is therefore interesting to consider whether T4's understanding of the connection between his work and the lab's overall goals may have differed had this line of research been established *before* he began his project, or even if he had the opportunity to see the emergence of this line of research before participating in his final *NOS Questionnaire* and *Interview*. Grasping the place of their research in the lab's goals also may have affected teachers' understanding of the influence of societal beliefs and values on the types of research conducted. Those whose projects did not directly connect to the lab's goals may have experienced difficulty seeing the potential impacts of their work.

It may also have been important for teachers to have opportunities to experience how scientists collaborate within and across disciplines and co-construct knowledge through a variety of modalities such as one-on-one interactions with a variety of individuals, lab meetings, and participation in other meetings or events that drew different researchers together around a common goal or focus. Finally, the capacity in which each teacher worked on their projects may have influenced their understanding of the variety of methods employed by researchers. Those who had more control over the design and implementation of their project and who were not constrained by scripted protocols may have developed a deeper appreciation for the variability of methodology.

Given these conjectures, an individual whose project was closely linked to the goals of the lab, who had multiple opportunities to work and interact with a variety of researchers and build upon the expertise of these researchers, yet who also maintained a degree of autonomy in the development of their project so that they could carry it out using methods they deemed most appropriate, may have had a research experience most conducive to increasing their sophistication with regard to NOS understanding. These considerations suggest that T1 would have had the most authentic research experience in terms of exposure to these aspects of NOS. Although participation in a formal lab meeting may have provided him with more opportunities to engage in intellectual exchange with a broader audience (e.g., graduate students), he was able to collaborate and exchange ideas related to his project with researchers who had a range of research foci (e.g., computer science, robotics, electrical engineering). Furthermore, T1's opportunity to observe a surgical procedure that drew upon he type of work that he was doing was unmatched by any other participant. This experience may have bolstered his NOS understanding in two ways. First, it could have provided a chance to see the implications of his project in a real-world context, thereby clarifying why such research might be valued by society. Observing the surgery itself may have also provided T1 with further insight into the ways in which modeling (in this case, primarily computer-based) helps researchers understand natural phenomena.

In contrast, T5's research experience was considerably more limited. T5 did not conceive of his own project and communicated through his *Daily Activity Logs* and *Bi-weekly Activity Interviews* that he primarily executed the same experimental protocol repeatedly. He apparently received limited opportunities for exposure to methodological variability and may have implicitly received the message that researchers follow invariant, scripted procedures in conducting their research. T5 also had limited contact with his PI or any other researchers beyond the graduate students who operated in and shared the lab space with him. T5 said that his research-related interactions with graduate students were primarily aimed at teaching him a procedure or part of the protocol for which he was responsible. Therefore, T5 had little opportunity to experience the ways in which researchers share their knowledge and build upon findings developed by others. Despite this limitation, it is worth considering potential affordances of T5's experiences with respect to interactions among researchers. Though he was the only study participant with a very limited range of people with whom he worked, T5's almost exclusive interaction with the graduate students in his lab may have facilitated a level of familiarity with the individuals with whom he worked unlike any other study participant. Coupled with the fact that he did not participate in group meetings that may have accentuated his relative newcomer status with respect to science research, T5's experience may have enabled him to participate in intellectual exchange with the graduate students in ways that actually served to highlight aspects of this focal construct.

T4's attendance at weekly lab meetings and a meeting involving participants from multiple labs provided him with opportunities to see how researchers exchange ideas and build upon one another's expertise in pursuit of a common research agenda. Yet the lack of connection between his project and the overall goals of his lab may have prevented a deeper understanding of societal implications of research conducted in his lab. It is therefore next important to consider to what extent teachers' NOS understanding may have actually changed during the time spent in their labs. An explanation of these changes and their potential linkage to participants' research experiences follow in Chapter V.

Teachers' NOS Understanding

The first analysis focused on teachers' NOS understanding, as reflected in their *NOS Questionnaire* and *Interview* responses. On both the pre- and post-instruction protocols, I first parsed the transcripts into idea units and then characterized each idea unit to a specific level within each construct that reflected its sophistication with respect to NOS understanding. The average number of idea units across teachers in pre-program NOS measures was 45 (ranging from 35 to 57), while the average number for post-program measures was 44 (ranging from 32 to 56). In this analysis, lower-numbered codes characterize idea units that reflect the lower levels of NOS sophistication, while higher numbers are assigned to idea units that reflect more refined levels of NOS understanding. The codes describing these varying levels of sophistication are next explained.

Intellectual Interdependence: Intra- and Interdisciplinary Exchange

As noted earlier, this construct emphasizes the intellectual interdependence that exists in the sciences. Individuals who understand this construct are expected to describe the ways that scientists draw upon the expertise of others (modern and/or their predecessors), both within and across science disciplines, to pursue common research goals and seek ways in which different research perspectives might converge to achieve their goals most effectively. In contrast, many laypeople may believe that scientists work in isolation in one narrow area of expertise without much interaction with or input from other researchers and without drawing upon different science disciplines in their work. Table 8 describes responses between these two extremes.

Table 8

Summary of NOS_Intellectual Interdependence Codes

Construct	**Code Level (decreasing sophistication)**	**Code Summary**
Intellectual Interdependence: Intra- and Interdisciplinary Exchange	NOS_II-5	Scientists draw upon the expertise of colleagues within and across science disciplines, both extant and their predecessors, in pursuit of common research goals. Information is shared through a variety of avenues (e.g., personal communications and interactions, publications, conferences, research protocols).
	NOS_II-4	Scientists draw upon the expertise of colleagues within and across science disciplines, both extant and their predecessors, primarily to expedite or streamline the research process. Information is shared through a variety of avenues.
	NOS_II-3	Scientists collaborate with colleagues within the same (or closely related) discipline. Interactions across disciplines are rare and/or are not emphasized. Information is shared primarily through personal interactions. Scientists build upon knowledge previously established by other researchers through books or publications, but the manner in which they do so is not clear.
	NOS_II-2	Scientists sometimes draw upon the knowledge of others, but this is not a central part of their disciplinary work. Knowledge of different disciplines may be necessary to think about their work, but no reference to the need for collaboration in order to do so.
	NOS_II-1	Scientists' work is highly specialized and focuses primarily on one particular topic/area of expertise with minimal interdisciplinary connections.

Pre/post comparisons of talk related to intellectual interdependence. Changes in study participants' understanding with respect to NOS_II as communicated in their *NOS Questionnaires* and *Interviews* are displayed in Figure 3.

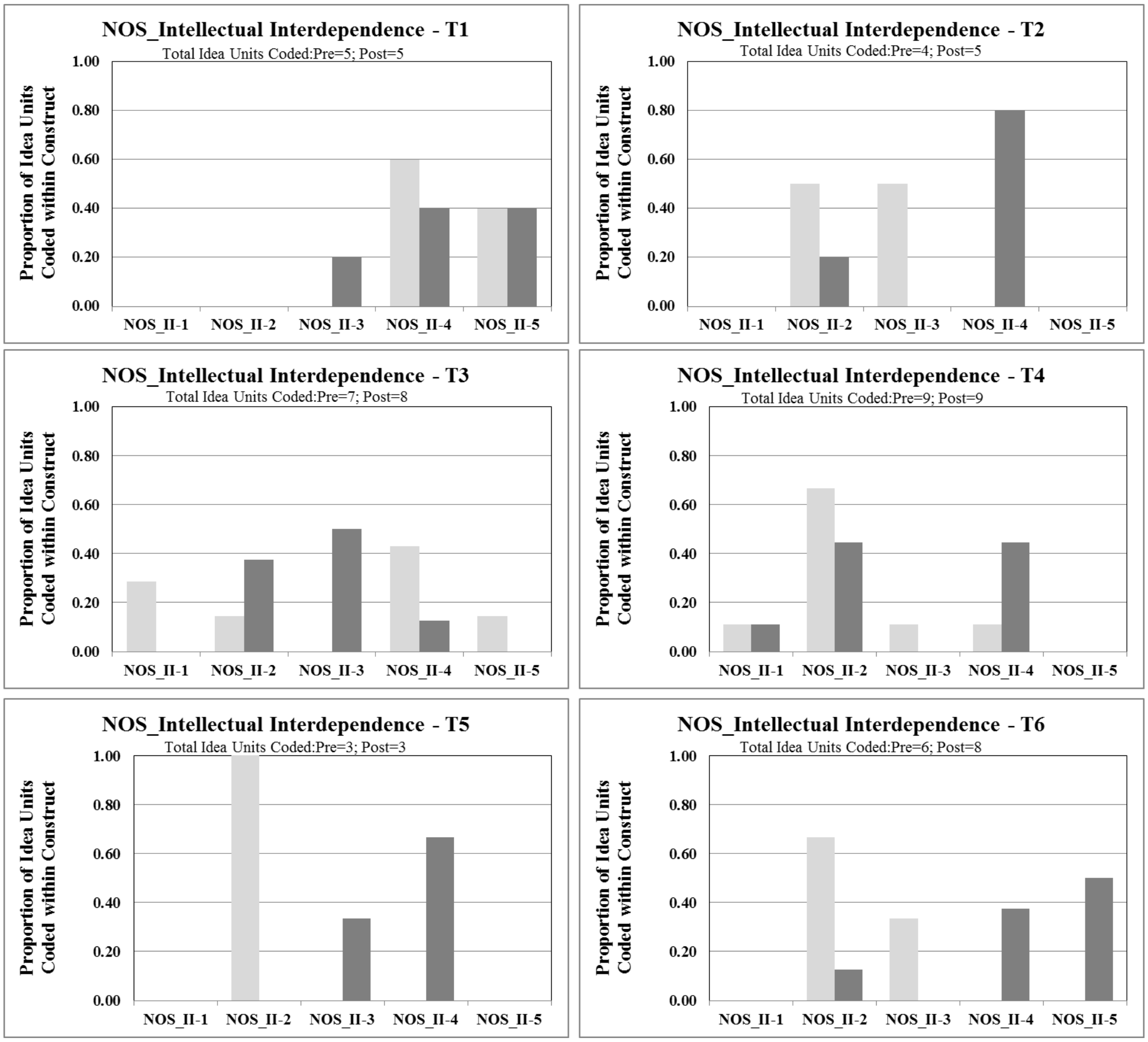


Figure 3. Proportion of idea units coded at each level of NOS_Intellectual Interdependence. Light gray bars represent pre-program data; dark gray represent post-program data.

In evaluating the data presented above, as well as that which will follow for subsequent constructs, it was important to establish what constituted meaningful pre/post changes in the idea units communicated by study participants. As Figure 3 shows, there is considerable variability in the sophistication of the participants’ responses, both before and after the program. Most of T1’s idea units were coded at the two highest levels. (IN fact, pre-program data for T1 showed that he possessed high levels understanding of *all* focal NOS constructs prior to his participation in his research experience, which was maintained in post-program measures.) In contrast, most of T6's idea units were coded at levels 2 and 3 before the program, whereas the majority was coded at levels 4 and 5 afterward.

Indeed, the graphs show an apparent shift for T2, T4, and T5. To add interpretive consistency beyond simple inspection of the graphical patterns, I categorized each study participant's pre-program and post-program responses in terms of their level of sophistication in relation to each construct. Based on the proportion of idea units coded at each level of the target construct, the participant's understanding of the construct was categorized as low, medium, or high prior to and following participation in research. Comparisons were then made to ascertain to what extent their understanding changed, if at all. Although a summary of these changes is provided following descriptions of the focal constructs, I first address each construct individually, focusing specifically on those individuals who *did* show change in understanding. In sum, with respect to the Intellectual Interdependence NOS construct, increases in understanding were established for most participants, specifically T2, T4, T5, and T6. These increases were most pronounced for T5 and T6, who both possessed low levels of understanding of this construct prior to participating in research, but who advanced to high levels following their participation in research.

My initial conjecture was that participation in research would increase participants' level of sophistication of NOS understanding. Interestingly, T2 and T5 exhibited change, despite having worked in more isolated research environments that may have limited their opportunity to see how scientists work together to draw upon the expertise of others in order to work toward a common goal. It could be that these participants had opportunities to see the graduate students with whom they were working interact with and build upon the ideas of others in ways that made the importance of this exchange more salient. Also, in the case of T2, her attendance at the imaging conference and a seminar may have been sufficient for helping her understand the role of such intellectual exchange.

Variability of Methodology

The Variability of Methodology construct emphasizes that scientists do not conduct their work by following the canonical scientific method, despite the pervasiveness of this model of scientific practice. Instead, it emphasizes that scientists employ different approaches (e.g., experiment-based, comparative study) that are selected because they are most appropriate for investigating their research questions. Individuals who possess more refined understandings of this construct would therefore convey an understanding of both of these dimensions of the variability of methodology within the scientific community. In contrast, those who lack understanding of this construct would instead focus on the scientific method, as well as an exclusive reliance on experimental research methods. The different levels of understanding falling between these two are described in Table 9.

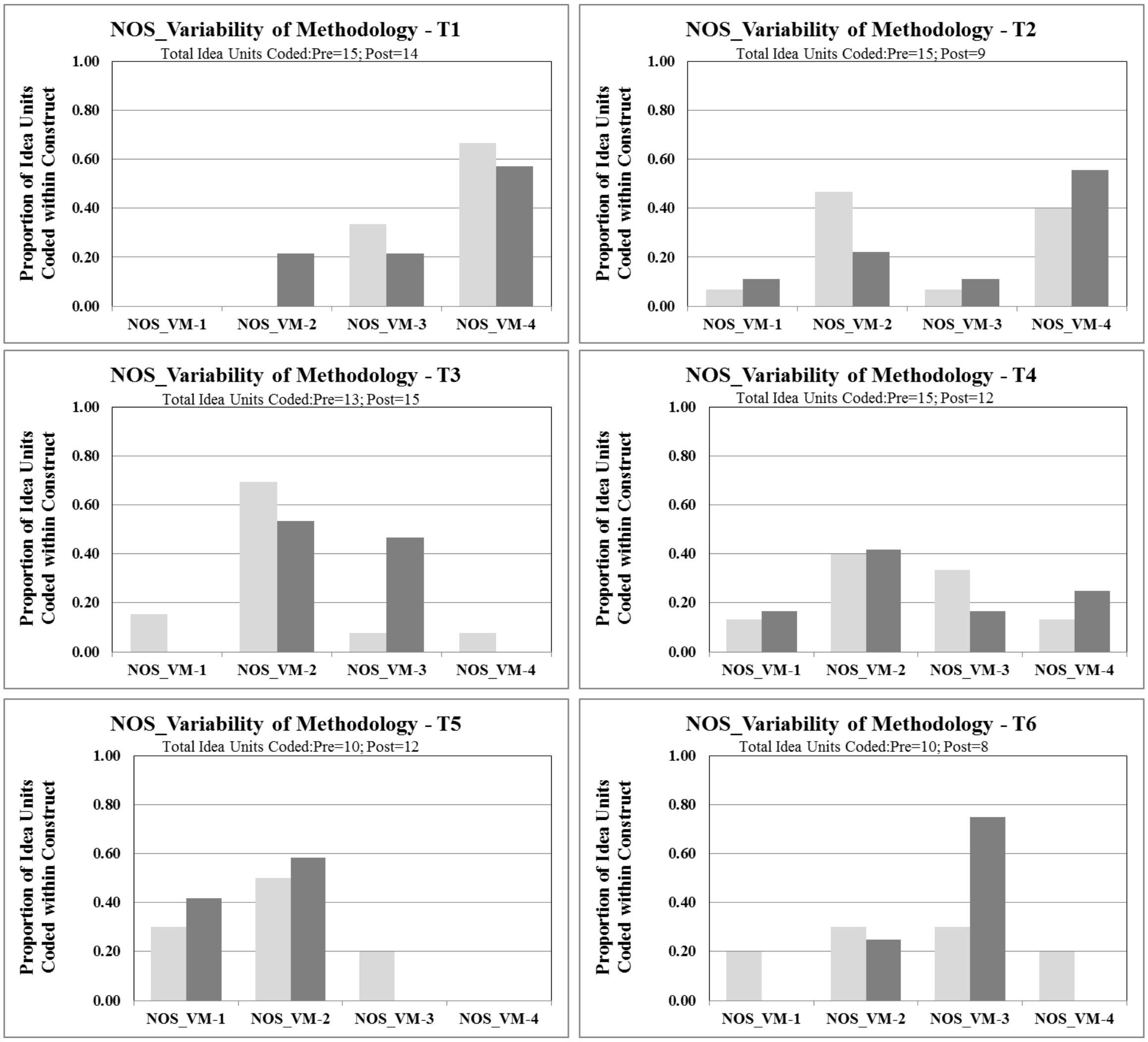
Table 9

Summary of NOS_Variability of Methodology Codes

Construct	**Code Level (decreasing sophistication)**	**Code Summary**
Variability of Methodology	NOS_VM-4	Scientists use different methodologies most appropriate for answering their particular research questions. Methods may involve experiments, comparative study, etc. Different scientists investigating similar topics/questions might use different approaches to conduct their research. Scientists do not necessarily follow the same sequence of steps portrayed by the scientific method, but instead revisit and revise their research questions and conjectures as needed based on their findings.
	NOS_VM-3	Scientists typically follow the same progression of steps in their research, but the methods employed in each of these steps differ based on discipline and/or research questions.
	NOS_VM-2	Scientists typically follow the same progression of steps in their research, but the specific methods employed in each of these steps differ based on discipline and/or research question. Regardless of discipline or questions pursued, all scientists employ experiments in their research.
	NOS_VM-1	Scientists all use the scientific method and experiments when conducting research.

Pre/post comparisons of talk related to variability of methodology.

Participants' ideas related to Variability of Methodology as communicated through their *NOS Questionnaires* and *Interviews* are summarized below in Figure 4.


NOS_Variability of Methodology - T1

NOS_Variability of Methodology - T2

NOS_Variability of Methodology - T3

NOS_Variability of Methodology - T4

NOS_Variability of Methodology - T5

NOS_Variability of Methodology - T6

Figure 4. Proportion of idea units coded at each level of NOS_Variability of Methodology. Light gray bars represent pre-program data; dark gray represent post-program data.

Although teachers varied with respect to the proportion of their ideas categorized at each level, only one teacher exhibited change with respect to this construct pre- to post-program. T2 showed improvement in her understanding, progressing from a medium level of understanding to high. Given that her project work consisted primarily of one type of activity (i.e., preparing bone samples for subsequent testing), this seems somewhat surprising. It may be that, again, her attendance at the imaging conference and a seminar provided her with opportunities to learn about different approaches to research.

Also, her work preparing the bone for two different types of testing (i.e., through imaging as well as mechanical testing) could have helped her thinking about addressing a research question using different methodologies for data collection.

In contrast, for T3, T4, T5, and T6, it appeared that variability in method was not accentuated in any way that influenced their NOS understanding, regardless of the type of research experience they had in the context of this RET program. Three of these teachers continued to make statements coded at level NOS_VM-1, even after the program was completed. Therefore, although some participants had the opportunity to participate in a variety of procedures used to generate different types of data (e.g., T3's work with techniques such as Western blotting and real-time polymerase chain reaction), their work nevertheless fell within a fairly narrow range of approaches toward research.

It is important to note that all study participants took part in laboratory-based projects, most grounded in experimental research approaches or engineering design. This was anticipated to some extent, given the nature of the program (e.g., none worked with researchers who typically engage in comparative studies, field-based methods, etc.) This could, in fact, have served to reinforce the idea that researchers rely primarily on experiment-driven (and/or, due to their placement in engineering labs, design-based) work. Additionally, the fact that most study participants were carrying out procedures dictated to them by others (typically graduate students) may have also reinforced the idea that scientists follow rigid procedures such as those depicted by the scientific method when conducting their work. This was likely compounded by the fact that, given the relatively short time period of their research experience, they did not have the opportunity to see an entire project through start-to-finish

One case is particularly thought-provoking. Figure 4 reveals that T5 exhibited the least-sophisticated understanding of the Variability of Methodology construct prior to his participation in research, yet he was the only study participant whose idea units communicated in *post-program* NOS measures fell entirely within the two lowest levels of the construct. T5 was also the only study participant who described his research activity as following the same experimental protocol on a daily basis. Although T5 utilized several different lab techniques in completing this protocol (e.g., coating gold samples with different polymers, then completing a series of different tests of the repellent properties of the coated surface), the repetition of the same structured set of procedures did little to help him value other approaches toward research. It may be that short-term projects that do not expose teachers to a broad range of research methods may not be apt vehicles for helping teachers understand the variability of methods that scientists undertake.

Scientific Knowledge: Generative

The Generative subdivision of the Scientific Knowledge asserts that individuals should comprehend that scientists strive to generate new knowledge about and understanding of the natural world. Additionally, they should recognize that, in generating these new understandings, researchers may revisit and refine existing knowledge, but that this is not their primary goal. Those who fail to acknowledge the importance of the advancement of knowledge in science and who instead convey that scientists solely strive to verify existing knowledge would be considered to have insufficient understandings of this aspect of NOS.

Table 10

Summary of NOS_Scientific Knowledge: Generative Codes

Construct	Code Level (decreasing sophistication)	Code Summary
Scientific Knowledge: Generative	NOS_SKGen-4	Scientists primarily strive to generate new knowledge. While they may revisit, verify, and subsequently refine existing knowledge during this process, the driving goal is to produce new understandings of natural phenomena.
	NOS_SKGen-3	Scientists strive to both verify existing knowledge and generate new knowledge. There is a fairly even balance between these two goals. Verification is aimed at reiterating existing knowledge in order to improve its validity.
	NOS_SKGen-2	Scientists primarily strive to verify existing knowledge. New knowledge may be generated during this process, but this is not the intended goal.
	NOS_SKGen-1	Scientists work to verify existing scientific knowledge in order to improve its validity.

Pre/post comparisons of talk related to the generative nature of scientific knowledge. In comparing data collected through pre-program and post-program NOS measures in relation to this aspect of NOS, very little difference can be seen in the responses provided by most participants. These results are summarized in Figure 5 and subsequently discussed in greater detail.

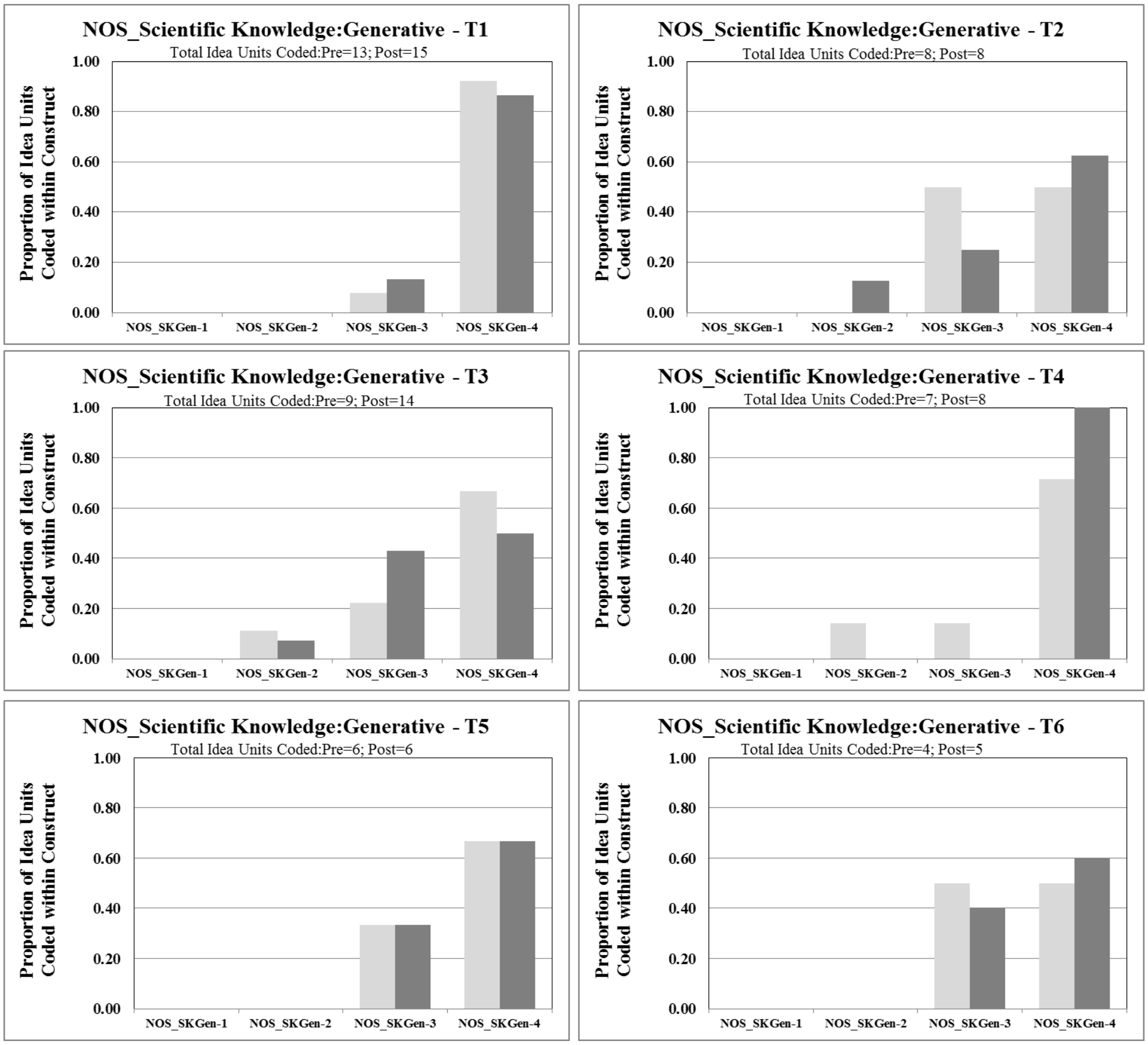


Figure 5. Proportion of idea units coded at each level of NOS_Scientific Knowledge: Generative. Light gray bars represent pre-program data; dark gray represent post-program data.

No study participants exhibited change in their understanding of this focal construct due largely to the fact that all study participants communicated relatively sophisticated conceptions of this construct even prior to their participation in research, which limited their potential for growth and therefore resulted in minimal to no change following this experience. The most notable (albeit subtle) shift was visible in T4's thinking about the generative nature of scientific knowledge, as in post-program NOS measures, *all* idea units that he communicated were coded to the highest level of the construct. It appears, then, that T4's research experience may have underscored his understanding and bolster his recognition of the importance of the role of knowledge generation over verification within the scientific community of practice. Although T4 struggled to see a direct connection between his project (which focused on the re-design of a haptic paddle device used in undergraduate courses) and the broader research goals of his lab, it is possible that the fact that his project was aimed at the generation of a new device through refinement of an existing system highlighted that researchers strive to produce new understandings of the phenomena on which they are focused and that, in this process, existing knowledge and interpretations might be revised and refined. This may have provided T4 with opportunities for growth along both of the primary dimensions of this construct. Given that the generative nature of scientific knowledge is one component of this focal construct and that the other aspect of this construct (i.e., the co-constructed nature of scientific knowledge) was also selected for focus in this study, I next explore changes in study participants' understanding of this aspect of the Scientific Knowledge construct.

Scientific Knowledge: Co-constructed

This aspect of NOS focuses upon the manner in which collaboration among scientists enables them to build, advance, and refine scientific knowledge. Unlike the Intellectual Interdependence focal construct, Scientific Knowledge: Co-constructed centers on the ways in which interactions among practicing scientists (as well as their predecessors) help them build knowledge, rather than focusing on their work in interdisciplinary environments. The levels used for evaluation of participants' understanding of this construct are provided in Table 11.

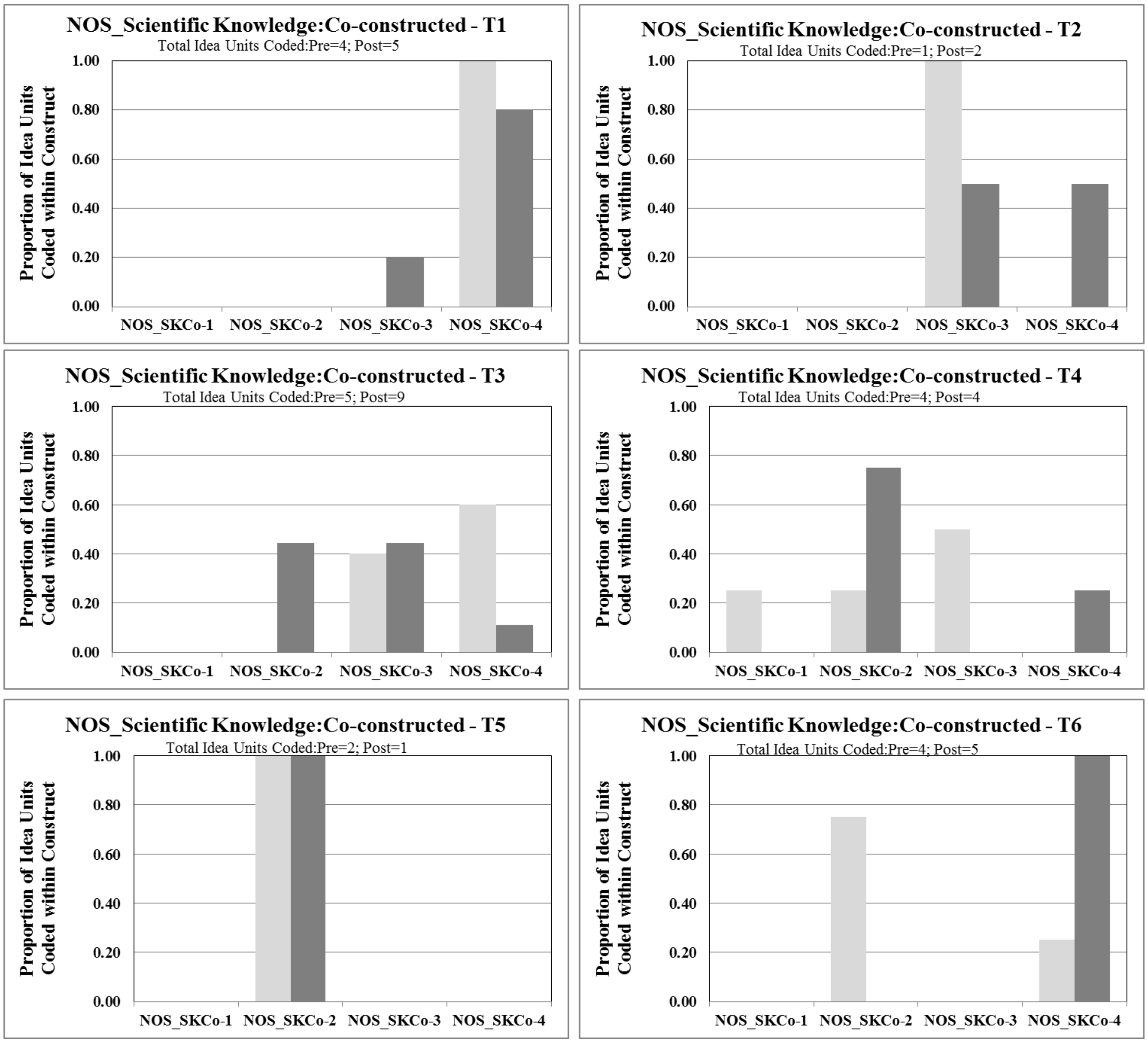
Table 11

Summary of NOS_Scientific Knowledge: Co-constructed Codes

Construct	**Code Level (decreasing sophistication)**	**Code Summary**
Scientific Knowledge: Co-constructed	NOS_SKCo-4	Collaboration among scientists (both among practicing scientists and their predecessors) leads to the building of scientific ideas and refinement of scientific knowledge. This results from scientists drawing upon the expertise of other researchers as they collaborate to construct this advanced scientific knowledge.
	NOS_SKCo-3	Scientists sometimes collaborate and share expertise in order to generate new knowledge and refine existing knowledge in scientific disciplines. Most of the interactions occur by practicing scientists consulting existing knowledge/research or technology developed by their predecessors.
	NOS_SKCo-2	Scientists develop new scientific knowledge in isolation, but may build upon the existing ideas established by their predecessors. Scientists may interact with one another in order to generate ideas, but the role of individual expertise in building knowledge is not emphasized.
	NOS_SKCo-1	Scientists develop knowledge independently. The ways in which scientists interact with one another in order to build knowledge are not acknowledged.

Two aspects of this construct were considered most likely susceptible to change through participation in research for this study. The first dimension focuses on the collaborations among scientists that facilitate the building of new knowledge, as well as refinement of existing knowledge, within the scientific community. The other dimension of this construct, similar to the Intellectual Interdependence construct, asserts that individuals with more sophisticated understandings of this construct would convey the importance of researchers drawing on specific areas of expertise in order to enable further knowledge co-construction. Those with naïve conceptions of this aspect of NOS, however, would fail to acknowledge the ways in scientists construct knowledge by drawing upon or contributing to the work of other researchers.

Pre/post comparisons of talk related to the co-constructed nature of scientific knowledge. Few pre/post differences were evident for most study participants with respect to this subcategory of the Scientific Knowledge construct. These within-construct shifts are represented in Figure 6.



NOS_Scientific Knowledge:Co-constructed - T1

Total Idea Units Coded:Pre=4; Post=5

NOS_Scientific Knowledge:Co-constructed - T2

Total Idea Units Coded:Pre=1; Post=2

NOS_Scientific Knowledge:Co-constructed - T3

Total Idea Units Coded:Pre=5; Post=9

NOS_Scientific Knowledge:Co-constructed - T4

Total Idea Units Coded:Pre=4; Post=4

NOS_Scientific Knowledge:Co-constructed - T5

Total Idea Units Coded:Pre=2; Post=1

NOS_Scientific Knowledge:Co-constructed - T6

Total Idea Units Coded:Pre=4; Post=5

Figure 6. Proportion of idea units coded at each level of NOS_Scientific Knowledge: Co-constructed. Light gray bars represent pre-program data; dark gray represent post-program data.

Of all study participants, only T3 and T6 exhibited pre/post change with respect to this construct, although in opposite directions. For T6, post-program responses reflected more sophisticated understanding of the co-constructed nature of scientific knowledge, while T3 exhibited a decrease in his understanding. Despite the level of detail reported in these teachers' *Daily Activity Logs* and *Bi-weekly Activity Interviews*, it is difficult to ascertain what unique aspects T6's research experiences may have drawn attention to this construct. It is possible that something inherent to the ways in which the people in her lab interacted with one another, as well as resources generated by predecessors, that provided the opportunity for T6 to observe the coordinated building of scientific knowledge. This could have occurred during their time working in the laboratory, and/or during their attendance at larger gatherings of researchers (i.e., during multi-lab meeting attended by T6). With respect to the decrease in understanding exhibited by T3, it is possible that his inability to articulate the role of the chemistry-based researchers in his lab was indicative of what may have caused this change. T3 appeared to be aware of different foci of those working on various aspects of his mentor PI's broader research goals, but he did not develop any deeper understanding of how their projects were connected and built upon one another. This may have served to undermine his level of understanding of the co-construction of knowledge, resulting in the decrease visible in this study.

For remaining study participants for whom no meaningful change was detected in relation to this construct, patterns of shifts in understanding were lacking. T1, for instance, again expressed relatively sophisticated ideas about the construct prior to his participation in research. These were maintained and generally reinforced through his time in the lab. In contrast, T5 began his research experience with less-refined understanding of this construct, yet this thinking also held across post-program measures. It is therefore unclear whether these participants' research experiences did not provide further insight into this particular construct, leaving their understanding largely unaffected, or if this construct is more resistant to change regardless of an individual’s existing level of comprehension.

Modeling and Inscribing: Types of Models

This construct describes the role of modeling within the scientific community of practice and how modeling practices within this community differ from other disciplines (e.g., architecture). Two dimensions of this construct contribute to this distinction: (1) scientists strive to model the natural world and these models take on a variety of forms (e.g., experiments, physical/structural, mathematical, computer-based); and (2) these models reduce phenomena to more interpretable forms, while simultaneously amplifying these phenomena in terms of its applicability to related phenomena. Therefore, an individual with a more sophisticated understanding of this construct would be able to articulate both of these aspects of the role of modeling in the scientific community of practice in order to convey its central role in scientific work. Individuals who fail to recognize how models are used in science would be considered lacking in understanding of this construct. Table 12 describes levels of understanding that would fall between these two extremes.

Table 12

Summary of NOS_Modeling Codes

Construct	**Code Level (decreasing sophistication)**	**Code Summary**
Modeling & Inscribing: Types of Models	NOS_Mod-4	Scientists primarily strive to model the natural world in their work. The models employed in this work take many forms (e.g., structural models, computational models, experiments, mathematical models, etc.) and are generated using a variety of methods. These models reduce the phenomenon to a more interpretable form, while simultaneously amplifying it in terms of its applicability to other, related phenomena.
	NOS_Mod-3	Scientists strive to model the natural phenomenon they are investigating using physical/structural models, computational models, and/or mathematical models to make some aspect of the world more understandable. Experiments are not viewed as a type of model.
	NOS_Mod-2	Models in science only consist of physical/structural models (e.g., atomic models, anatomical models) meant to represent some aspect of the world on a more manageable scale.
	NOS_Mod-1	Scientists use models in their work but no explanation is provided about how they are used, or there is no acknowledgement of the use of models in science.

Pre/post comparisons of talk related to modeling. Like most other constructs, pre/post change with respect to NOS_Modeling was visible only for some study participants. These results are depicted in Figure 7.

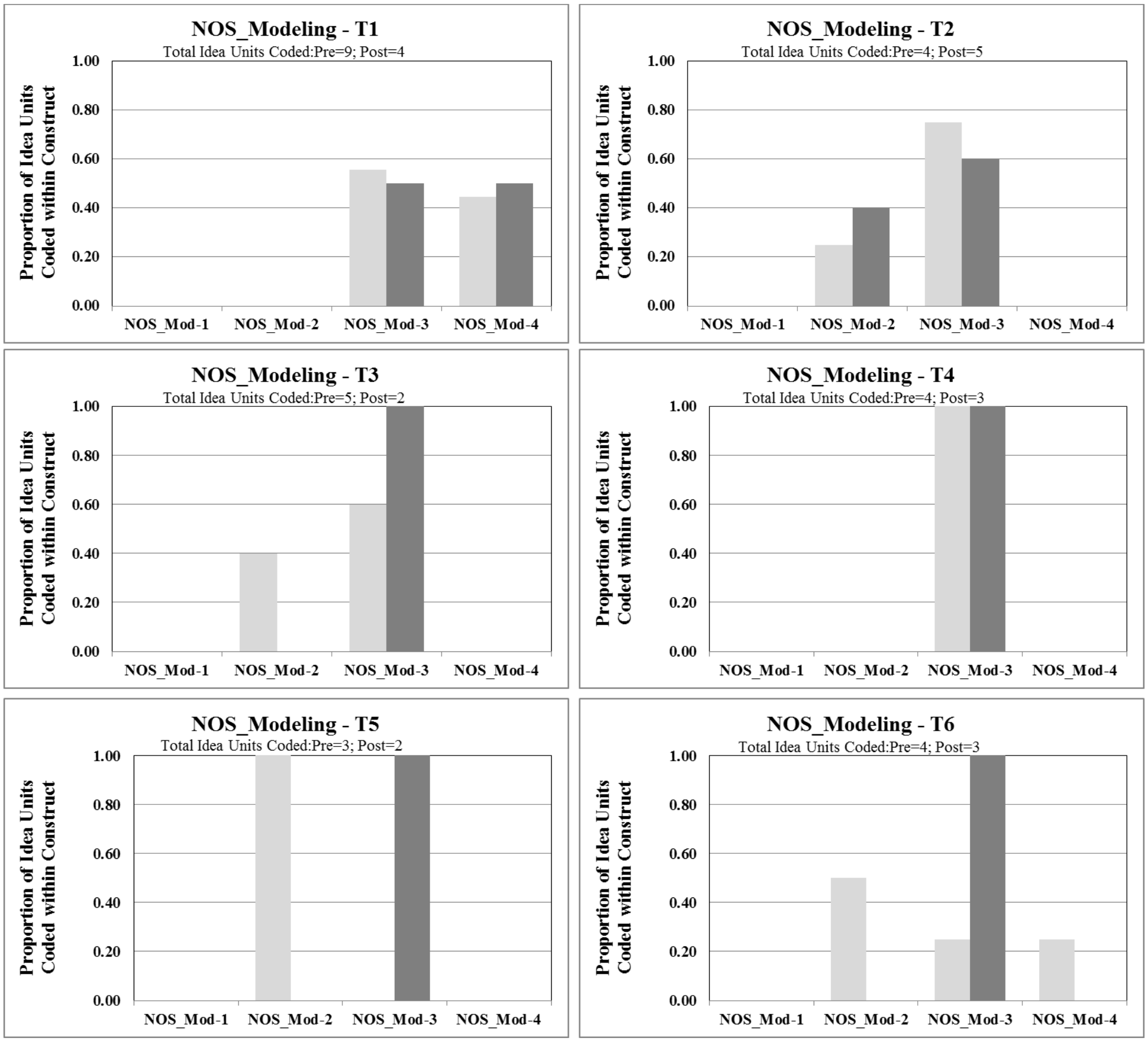


Figure 7. Proportion of idea units coded at each level of NOS_Modeling. Light gray bars represent pre-program data; dark gray represent post-program data.

Only T3, T5, and T6 exhibited meaningful change with respect to the modeling construct across pre/post NOS measures. All showed increases in the proportion of idea units coded as NOS_Mod-3 (one of the two higher-level codes) and an elimination of ideas coded to NOS_Mod-2, a lower-level code, in post-program measures. Some aspect of these participants' research experience therefore made the role of modeling in the scientific community of practice more visible and/or understandable to them. For instance, all of these participants understood and were able to articulate how their work related to everyday contexts beyond their labs, thereby helping them comprehend that scientists strive to model phenomena in the world around them. Other study participants, however, were also able to convey such connections without demonstrating change in relation to this construct, so this was not the only contributing factor to such change.

Also, although much of T3's, T5's, and T6's work was experiment-driven, none participant came to recognize experimentation as a form of modeling. This pattern also held true across most other participants (T1 being the exception). This is not surprising, given that these teachers likely participated in experiment-based lab activities in their own education (and engaged their own students in such activities), yet had not developed deeper understanding of experiments as models. Clearly, conducting experiments does not foster recognition of experiments as scientific models. T3, T5, and T6 might have seen how *portions* of their experiments were designed to model aspects of real-world phenomena, however. Although they did not recognize an entire experiment as a model, they were able to appreciate how different parts of larger experiments modeled aspects of the world in different ways. This could have contributed to their shifting understanding of this construct, particularly in relation to the variety of models employed by researchers.

Historical and Contemporary Context: Beliefs and Values

It is important to understand the influence of the beliefs and values of scientists and the society in which they do their work on the types of questions pursued, the means by which these questions are investigated, and the methods and lenses of analysis employed in science research. Additionally, individuals should be critical in their consideration of the role of support from various resources (e.g., funding from government agencies and/or private foundations) in the selection of research questions and methodologies. Those who understand these influences on three primary dimensions of this construct (personal values/beliefs, societal values/beliefs, and sources of support) would possess sophisticated beliefs about this focal construct. In contrast, individuals who maintain naïve understandings of this construct would lack understanding of these influences, believing instead that science and scientists are unbiased and objective by nature.

Table 13

Summary of NOS_Context: Beliefs and Values Codes

Construct	**Code Level (decreasing sophistication)**	**Code Summary**
Historical & Contemporary Context: Beliefs & Values	NOS_CB&V-4	Societal values, as well as scientists' personal values and beliefs about the world, all influence the types of questions pursued, methods employed, and approaches to analysis in research. Societal beliefs and values may influence the types of research supported by different funding sources, such as the federal government.
	NOS_CB&V-3	Societal values may influence the types of questions valued in scientific research and/or the methods used to pursue these questions. Scientists' personal values and beliefs may influence the types of questions that they investigate, but they remain objective when selecting their methods for investigating these questions or interpreting their results.
	NOS_CB&V-2	Societal values may influence the types of questions that are valued in scientific research. Individual scientists, however, are objective and do not allow their personal beliefs or values to influence the research they pursue, although they may build upon their own background knowledge when developing their research questions and methods for investigating them.
	NOS_CB&V-1	Societal and scientists' personal values and beliefs have no impact on the types of questions researchers pursue and the means by which they investigate them, as scientists and their work must remain objective. While scientists may require some form of background knowledge (e.g., familiarity with certain laboratory techniques) to conduct research, this knowledge does not influence their work so that they remain unbiased in all aspects of their work.

Pre/post comparisons of talk related to the role of beliefs and values in science research. Results with respect to the final focal NOS construct show that only one study participant, T2, exhibited change in understanding. These results are reflected in Figure 8 below.

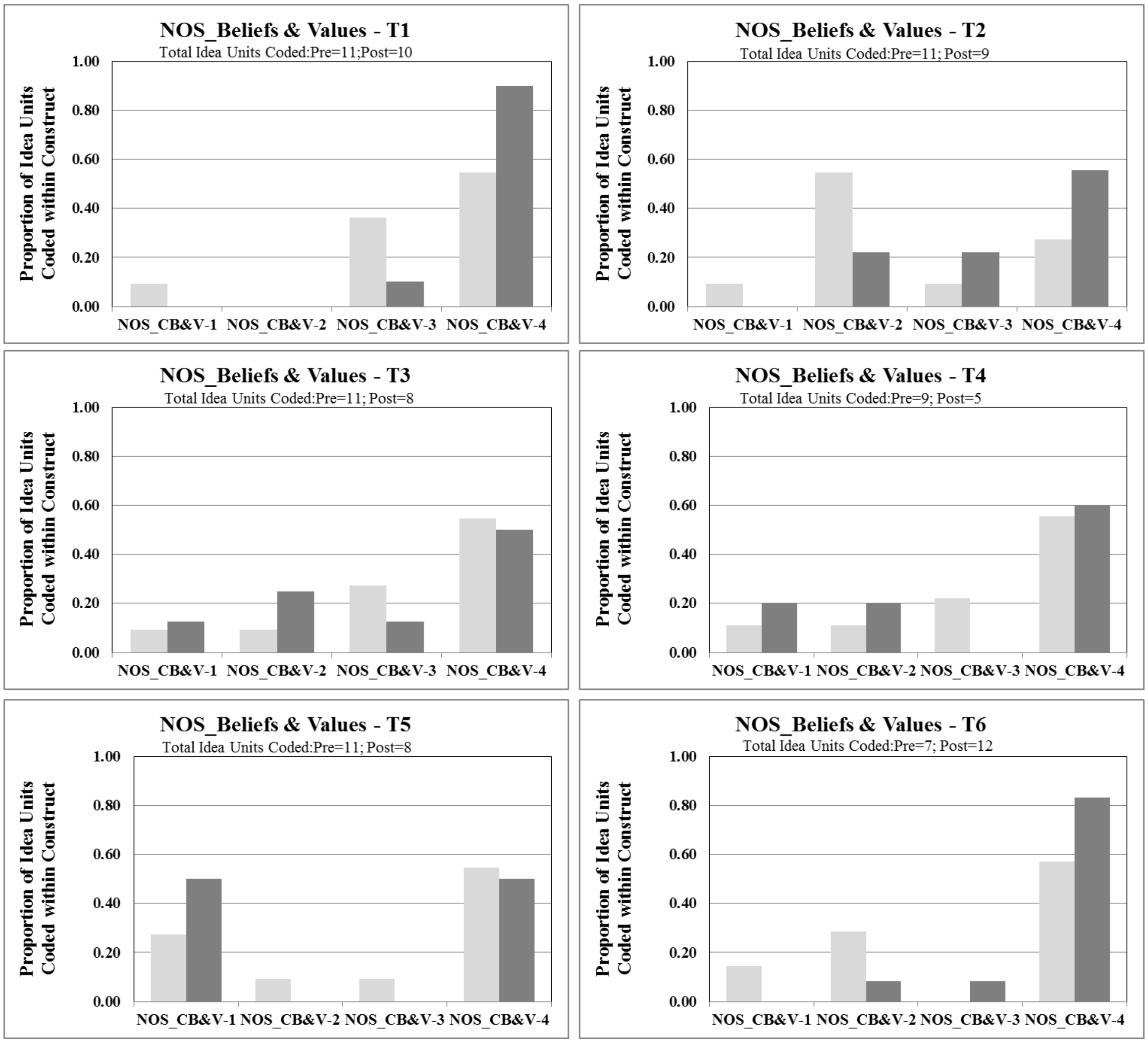


Figure 8. Proportion of idea units coded at each level of NOS_Context: Beliefs and Values. Light gray bars represent pre-program data; dark gray represent post-program data.

Aspects of T2’s research experiences may have helped underscore the influence of beliefs and values on the scientific community of practice. In the case of T2, she was able to articulate clearly the potential implications of her work with human bone samples for diagnosis of osteoporosis. T2’s work on a project utilizing materials of a visibly recognizable scale (i.e., working with whole bone rather than at a cellular or molecular level) may have facilitated the formation of these connections.

Most study participants who did not show change did so because they already possessed higher levels of understanding of this construct. Of the four teachers for whom this was the case (T1, T3, T4, and T6), two are worth closer examination. Both T1 and T6 shifted from sharing some ideas that were categorized at lower levels pre-program, (despite maintaining a relatively advanced understanding of this construct overall) to overwhelmingly high-level ways of thinking about the influence of beliefs and values on the scientific community of practice. As noted previously, T1’s observation of a surgery that relied upon research similar to his work likely provided a rich opportunity for him to witness potential real-world impacts of his work. This helps highlight the reason why such work is valued in the scientific community, as well as the world at large. This may have bolstered T1’s appreciation of how societal values and beliefs drive the types of research pursued. T1 also discussed in within-program measures that the PI with whom he worked was nearing the submission of a grant application for research funding support. His exposure to this process may have also contributed to T1’s understanding of this construct. Similarly, T6’s ability to describe the ultimate goal of her work as being related to the development of a synthetic substitute for human bone may have been accentuated by the fact that the lab was in the end stages of producing a product for an outside company, therefore the connection of the lab’s research to the world at large may have been contextualized for T6. T2’s, T1’s, and T6’s ability to envision the applications of their labs’ work for human benefit may have enabled them to think more deeply about how societal beliefs and values, which may in part be influenced by a perceived need, may influence the types of projects pursued in science.

It is notable that some study participants who were also able to describe real-world applications of their projects (e.g., T3 and T5) did not show any notable shifts in the sophistication of their understanding of this construct. This is especially interesting in the case of T5, who maintained only a mid-range level of understanding of this construct. This could have been due their work being focused on a much smaller scale (i.e., the molecular biology level for T3 and the chemical level for T5) which may have inhibited their ability to make associations between their work and the beliefs and values of society as effectively as T1, T2, T6. The research experience of T4, which focused on the re-design of a device for use in an undergraduate course, may have similarly obscured the potential influences of beliefs and values on the types of research that is pursued.

Summary of Teachers' Changes in NOS Understanding

Although changes in the sophistication of participating teachers' thinking about each focal construct has been discussed in detail and cross-case comparisons made within each construct, it is important to look at overall patterns of change across all constructs and participants. This data is therefore summarized below in Table 14.

Table 14

Summary of Changes in Teachers' Understanding of NOS Constructs

Teacher ID	**Construct**					
	Intellectual Interdependence	Variability of Methodology	Scientific Knowledge: *Generative*	Scientific Knowledge: *Co-Constructed*	Modeling & Inscribing: *Types of Models*	Historical & Contemporary Context: *Beliefs & Values*
T1	H↔ H	H↔ H	H↔ H	H↔ H	H↔ H	H↔ H
T2	M ↑ H	M ↑ H	H↔ H	H↔ H	M ↔ M	M ↑ H
T3	M ↔ M	M ↔ M	H↔ H	H ↓ M	M ↑ H	H↔ H
T4	L ↑ M	M ↔ M	H↔ H	M ↔ M	H↔ H	H↔ H
T5	L ↑↑ H	L ↔ L	H↔ H	M ↔ M	M ↑ H	M ↔ M
T6	L ↑↑ H	M ↔ M	H↔ H	M ↑ H	M ↑ H	H↔ H

Letters to the left of each arrow indicate participant understanding prior to program participation. Letters to the right of each arrow indicate post-program understanding. L reflects low levels of understanding, M reflects medium levels of understanding, and H indicates high levels of understanding. Arrow directionality indicates the direction of change (none, increase, or decrease). Multiple arrows reflect a change of two levels of understanding (e.g., low to high).

Table 14 reveals that, overall, change with respect to focal constructs was inconsistent across constructs and participants. It is important to note, however, that all study participants did exhibit pre/post shifts toward more sophisticated understandings of at least one focal construct. (The one exception to this was T1, who already possessed fairly sophisticated NOS understanding prior to participation in this study.) These results indicate that participation in different types of research experiences, even those couched primarily within one field (i.e., engineering), can provide insights into different aspects of NOS. Two participants, T2 and T6, showed positive change in half of the constructs. As the table shows, several of the teachers showed change in understanding intellectual interdependence and in modeling and inscribing; there was much less change in understanding the variability of methodology, the co-construction of scientific knowledge, or the importance of beliefs and values in science. Interestingly, all six of the participants were rated “high” on understanding the generative nature of scientific knowledge both prior to and following their research. It is, however, important to consider to what extent the shifts that did occur may have also manifested in the ways study participants thought about classroom instruction related to NOS. These connections are next explored.

Teachers’ Instruction and NOS

Despite the inconsistencies in changes in NOS understanding communicated through participants’ *NOS Questionnaires* and *Interviews*, it is nevertheless important to consider the extent to which any changes in NOS understanding might be reflected in teachers’ talk about and enacted instruction as conveyed through *Instructional Interviews* and *Instructional Observations*, respectively. Changes in these two components (i.e., talk about instruction and enacted instruction) are described below, and connections between these changes and participants’ NOS understanding are discussed.

Instructional Interviews

Like the data collected through NOS measures, analysis of *Instructional Interview* data focused on pre/post comparisons of the sophistication with which study participants discussed each of the focal constructs in relation to classroom instruction. These analyses aimed at describing the extent to which the teachers’ thinking about instruction related to NOS changed following participation in research. *Instructional Interview* transcripts were parsed into idea units in the same manner as NOS data, and these idea units were assigned to levels within the constructs based on the sophistication of understanding reflected. For *Instructional Interviews*, the average number of idea units generated across participants in pre-program interviews was 47, ranging from 41 to 61, while the post-program average was 46, ranging from 34 to 62. The coding schemes describing the different levels of each focal construct, which built upon those developed for NOS measures, and results of related analyses are presented below.

Intellectual interdependence. The intradisciplinary and interdisciplinary exchanges that take place among scientists enable them to draw upon the expertise of others both within and across science disciplines to pursue common research goals. Teachers who are able to think in sophisticated ways about how to communicate this understanding to students through classroom instruction would discuss the importance of providing opportunities for students to engage in intra- and interdisciplinary exchange in order to develop an appreciation of intellectual interdependence within the scientific community. The teacher might also describe how he or she would design and facilitate classroom activities to highlight these interdisciplinary connections, such as specific plans for students to work with peers in science classes of other disciplines, and/or with practicing scientists in different fields of study, to further their understanding of this construct. In contrast, teachers with less sophisticated understandings of how this focal construct might be addressed through classroom instruction would fail to see connections among the content addressed in their course and any other science course and would also overlook the potential benefits of students working with interdisciplinary concepts. Table 15 summarizes the different levels of responses that address this construct in relation to classroom instruction.

Table 15

Summary of InstructionTeacherTalk_Intellectual Interdependence Codes

Construct	**Code Level (decreasing sophistication)**	**Code Summary**
Intellectual Interdependence: Intra- and Interdisciplinary Exchange	InsTT_II-5	Teacher talks about the need to facilitate activity and discussion to help students understand the importance and implications of connections among different science disciplines, as well as ways that individuals may specialize in and share knowledge across and within disciplines. Teacher describes specific opportunities and/or plans for integrating science disciplines through intra- and interdisciplinary exchange with students in other science disciplines and/or with practicing scientists within his or her instruction.
	InsTT_II-4	Teacher talks about the need to help students understand the importance and implications of connections between different science disciplines and the ways researchers collaborate with individuals across OR within disciplines. Teacher describes specific opportunities and/or plans for intra- and/or interdisciplinary exchange among students within his or her individual classes.
	InsTT_II-3	Teacher discusses the fact that students should understand that researchers work in cross-disciplinary teams. Teacher talks generally about connections between his or her course content and content addressed in other courses. Teacher describes importance of asking students to think about interdisciplinary topics/issues but does not describe plans for students to do so through intra- or interdisciplinary exchange.
	InsTT_II-2	Teacher acknowledges that students should understand that researchers work collaboratively, but does not emphasize the intra- and interdisciplinary composition of research teams. Teacher does not emphasize nor discourage interdisciplinary thinking. Teacher acknowledges opportunities for interdisciplinary instruction but does not describe any plans to provide such experiences. Teacher discusses opportunities for students to share information to expand the breadth of topics addressed, or share data with one another for the purpose of experimental replication, but does not explain how this may be built upon to expand student understanding of an interdisciplinary concept.
	InsTT_II-1	Teacher does not acknowledge/address intellectual interdependence in any way. Teacher does not in any way discuss how thinking about interdisciplinary concepts may help students understand science.

Pre/post comparisons of talk related to intellectual interdependence. Overall, mixed results were found in the ways in which study participants talked about helping (or planning to help) their students develop understanding of the intellectual interdependence of the scientific community of practice, as seen in Figure 9.

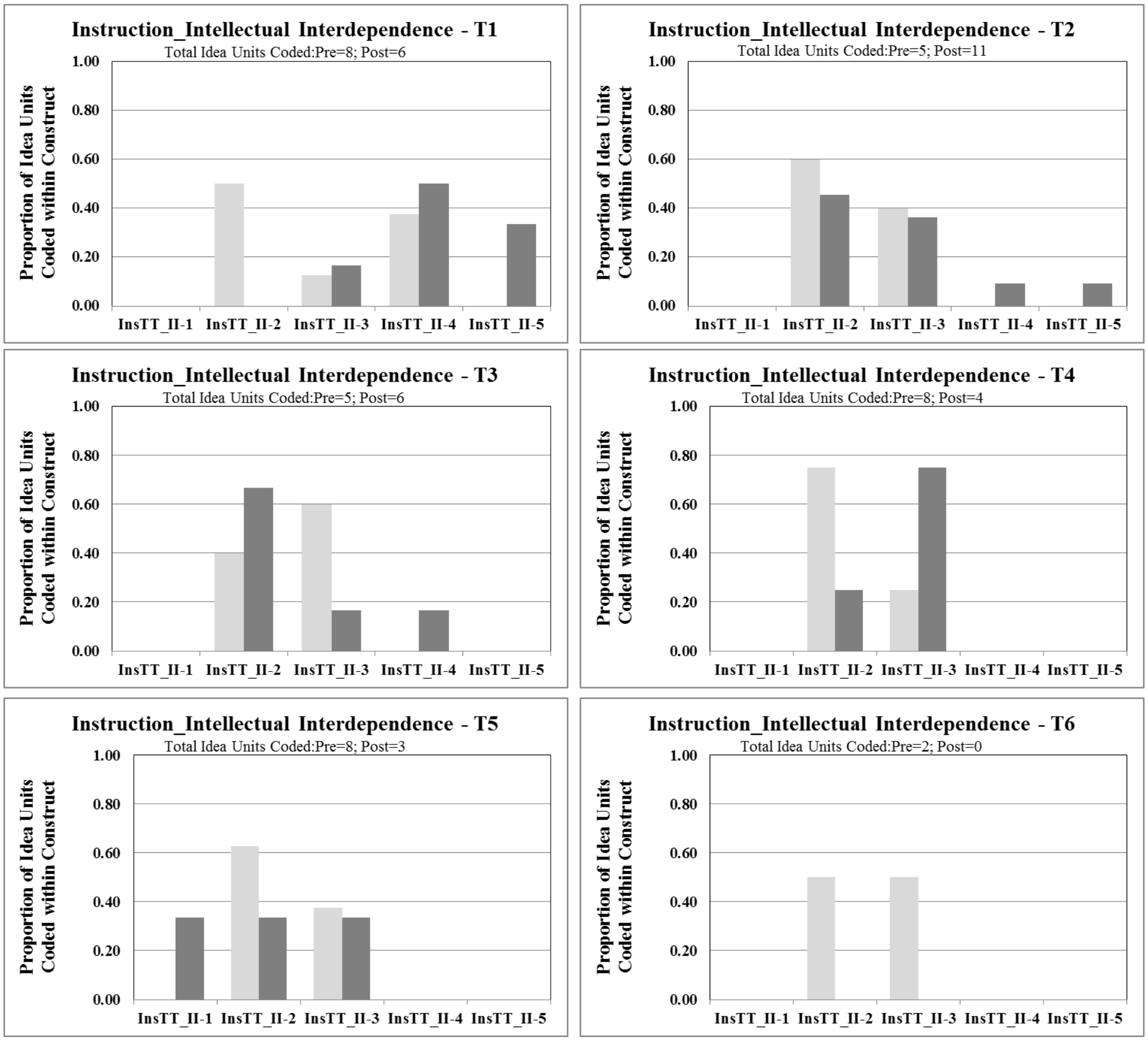


Figure 9. Proportion of idea units coded at each level of InsTT_Intellectual Interdependence. Light gray bars represent pre-program data; dark gray represent post-program data.

As with NOS data, pre- and post-program data from participants' discussion of each focal construct with respect to classroom instruction was categorized as reflecting high, medium, or low levels of understanding and pre/post changes noted. Based on this criterion, T1, T2, and T4 showed change toward more sophisticated thinking about teaching related to this construct. These results, along with those presented previously in Figure 3 and Table 14, reflect that T2 and T4 increased in their sophistication with which they discussed the Intellectual Interdependence construct both in terms of NOS understanding and classroom instruction. This suggests that their understanding of this aspect of NOS was refined through participation in research and that they were able translate this new understanding into the instructional context. T1 showed comparable refinement of his thinking about this construct in relation to instruction. Therefore, although he began with and maintained relatively sophisticated understanding of Intellectual Interdependence within the scientific community, T1 was better able to import this understanding into his thinking about classroom instruction following his participation in research.

In contrast, although T5 and T6 communicated more sophisticated understandings of this construct following their research experience, this new understanding was not carried into their thinking about instruction. In fact, T6's ideas about how to address this construct in the classroom actually decreased in their sophistication. These mixed outcomes across participants suggest that changes in teachers' NOS understanding related to Intellectual Interdependence do not ensure that corresponding changes will necessarily occur in their thinking about classroom instruction related to this construct.

Variability of methodology. This construct emphasizes the different approaches employed by researchers as they conduct their work, thus dispelling the notion of the existence of a universal, experiment-driven scientific method. Teachers who maintain more sophisticated understandings of the Variability of Methodology construct with respect to classroom instruction would therefore stress that students should understand that different approaches to research are employed by scientists both within and across disciplines in order to address different research questions. They would also convey that students should understand that not all scientists rely on experiments to generate their data, nor do they follow the rigidly-designed steps of the scientific method when conducting their research. These teachers with more refined understanding of instruction related to this focal construct would therefore provide specific examples of how he or she could convey such understanding to students through their class work. Those individuals who are less sophisticated in their thinking about instruction related to the Variability of Methodology construct, however, would emphasize the importance of students engaging in activities that reinforce understanding of the scientific method and that place value solely on experiment-based research. The need for structured, scripted lab activities would therefore be highlighted by these individuals in lieu of more authentic investigations. These two extremes, as well as levels of understanding that would fall between them, are summarized in Table 16.

Table 16

Summary of InstructionTeacherTalk_Variability of Methodology Codes

Construct	**Code Level (decreasing sophistication)**	**Code Summary**
Variability of Methodology	InsTT_VM-4	Teacher stresses the need for students to understand the different approaches to research employed by scientists both within and across disciplines, noting that not all scientists rely on experiment-driven data. Teacher emphasizes that different methodologies enable researchers to pursue different research questions and that they do not all follow a set of rigidly-defined steps, therefore addressing the lack of a universal scientific method. Teacher expresses desire to provide opportunities for students to engage in activities that allow them to determine their own methods for answering a question and provides concrete examples of how he or she does or plans to do so.
	InsTT_VM-3	Teacher acknowledges that students should understand that researchers employ different techniques when attempting to answer their research questions, but emphasize that all still use the scientific method OR that they rely on experiments to generate data. Teacher expresses desire to provide students with the opportunity to engage in more authentic research activities, but does not communicate clear plans for doing so. Teacher may discuss need for engaging students in more structured lab activities in order to help develop their understanding of equipment or particular concepts, but drawbacks of this approach are acknowledged and importance is therefore placed more on open-ended investigation.
	InsTT_VM-2	Teacher acknowledges that students should understand that researchers employ different techniques when attempting to answer their research questions, but emphasize that all use the scientific method AND rely on experiments to generate data. Teacher expresses value of or desire to provide opportunities for students to engage in more authentic research activities, but does not consider this a realistic expectation given various constraints on teaching and/or students' background knowledge. Teacher discusses instructional value of more structured and scripted investigations. Teacher may explain that students are permitted to pursue different approaches to certain class assignments, but this is not carried over into students' investigations.
	InsTT_VM-1	Different approaches to research employed by scientists are not emphasized. Teacher emphasizes that scientists follow the scientific method and rely on experiments to generate data. Teacher does not describe any desire or need to engage students in more authentic research activities and emphasizes the value of structured, scripted investigations.

Pre/post comparisons of talk related to variability of methodology.

Participants' ideas about instruction related to Variability of Methodology as communicated through their *Instructional Interviews* are summarized in Figure 10.

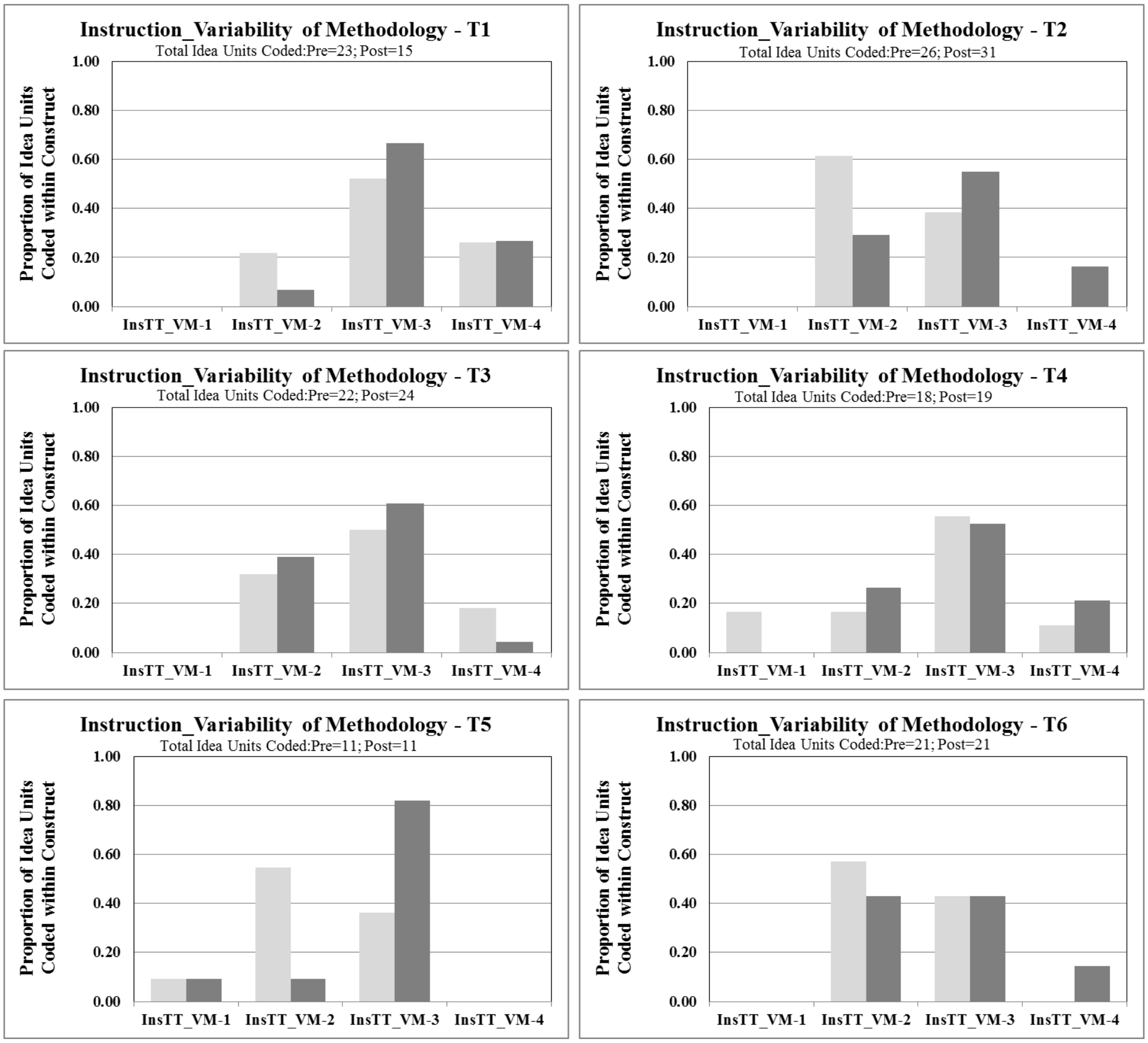


Figure 10. Proportion of idea units coded at each level of InsTT_Variability of Methodology. Light gray bars represent pre-program data; dark gray represent post-program data.

No study participants showed pre- to post-program changes in their thinking about instruction related to Variability of Methodology. Recall, however, that only one study participant, T2, exhibited change with respect to this construct across NOS measures. Therefore, although T2 appeared to acquire deeper understanding of this construct strictly in regard to thinking about NOS, she was unable to discuss how she might help students better understand the different approaches to research used by scientists in more refined ways following participation in research. T5's results are somewhat surprising given that his post-program NOS responses were coded entirely at the two lowest levels of the construct, yet when talking about this aspect of NOS in relation classroom instruction, the majority of idea units that he communicated received the higher-level InsTT_VM-3 code. This suggests that, although T5 was able to talk about instruction related to Variability of Methodology in more sophisticated ways following his research experience, this understanding was not generalized to his personal beliefs about NOS. Therefore, although his protocol-based research activities reinforced the notion of an experiment-driven scientific method, he still placed value on engaging students in more authentic investigations that may not rely on such universal methods.

Scientific knowledge: Generative. According to the Scientific Knowledge: Generative construct, scientists strive to generate new knowledge and, in doing so, may revise or refine existing scientific knowledge. Teachers who are capable of communicating sophisticated ideas about this construct would stress the importance of helping students understand these aspects of NOS. They would also acknowledge that most school science disproportionately engages students in the verification of existing knowledge and pursuit of expected results rather than the generation of new understanding of natural phenomena. Consequently, these individuals would describe specific plans for engaging students in open-ended investigations to help build their understanding of concepts, including opportunities to reason about unexpected or discrepant data. In contrast, those teachers who maintain less sophisticated understanding of the generative nature of scientific knowledge would convey reliance upon students working on investigations aimed at yielding expected results in order to reinforce understanding of a concept. Table 17 summarizes the different levels of understanding related to the Scientific Knowledge: Generative construct.

Table 17

Summary of InstructionTeacherTalk_Scientific Knowledge: Generative Codes

Construct	**Code Level (decreasing sophistication)**	**Code Summary**
Scientific Knowledge: Generative	InsTT_SKGen-4	Teacher emphasizes that students should understand that scientists primarily work on projects that strive to generate new knowledge and advance scientific understanding of natural phenomena rather than verify it. Teacher acknowledges that most school science focuses on verification or the pursuit of expected results and describes plans for engaging students in open-ended investigations that may result in the generation of different and unexpected outcomes. Teacher emphasizes the importance of examining discrepant or unexpected results for moving scientific knowledge forward.
	InsTT_SKGen-3	Teacher emphasizes that students should understand that scientists work to both generate new and verify existing knowledge about natural phenomena OR acknowledges that school science focuses primarily on verification and the pursuit of expected outcomes. Teacher expresses desire to engage students in open-ended investigations that provide the opportunity for consideration of differences in results and their importance in moving scientific knowledge forward, but does not describe any specific plans for doing so.
	InsTT_SKGen-2	Teacher emphasizes that students should understand that scientists primarily work to confirm or verify existing knowledge and that new knowledge or understanding rarely emerges. Teacher expresses desire to engage students in an investigation that would provide them with an opportunity to discuss why they may have obtained different results, but does not emphasize the way in which this may still lead to the development of new knowledge.
	InsTT_SKGen-1	Teacher does not stress the role of knowledge development in science. Teacher describes importance of students participating in investigations that are expected to yield particular results in order to reinforce understanding of a concept.

Pre/post comparisons of talk related to the generative nature of scientific knowledge. Changes in study participants' understanding with respect to the generative nature of scientific knowledge as communicated in their *Instructional Interviews* are displayed in Figure 11.

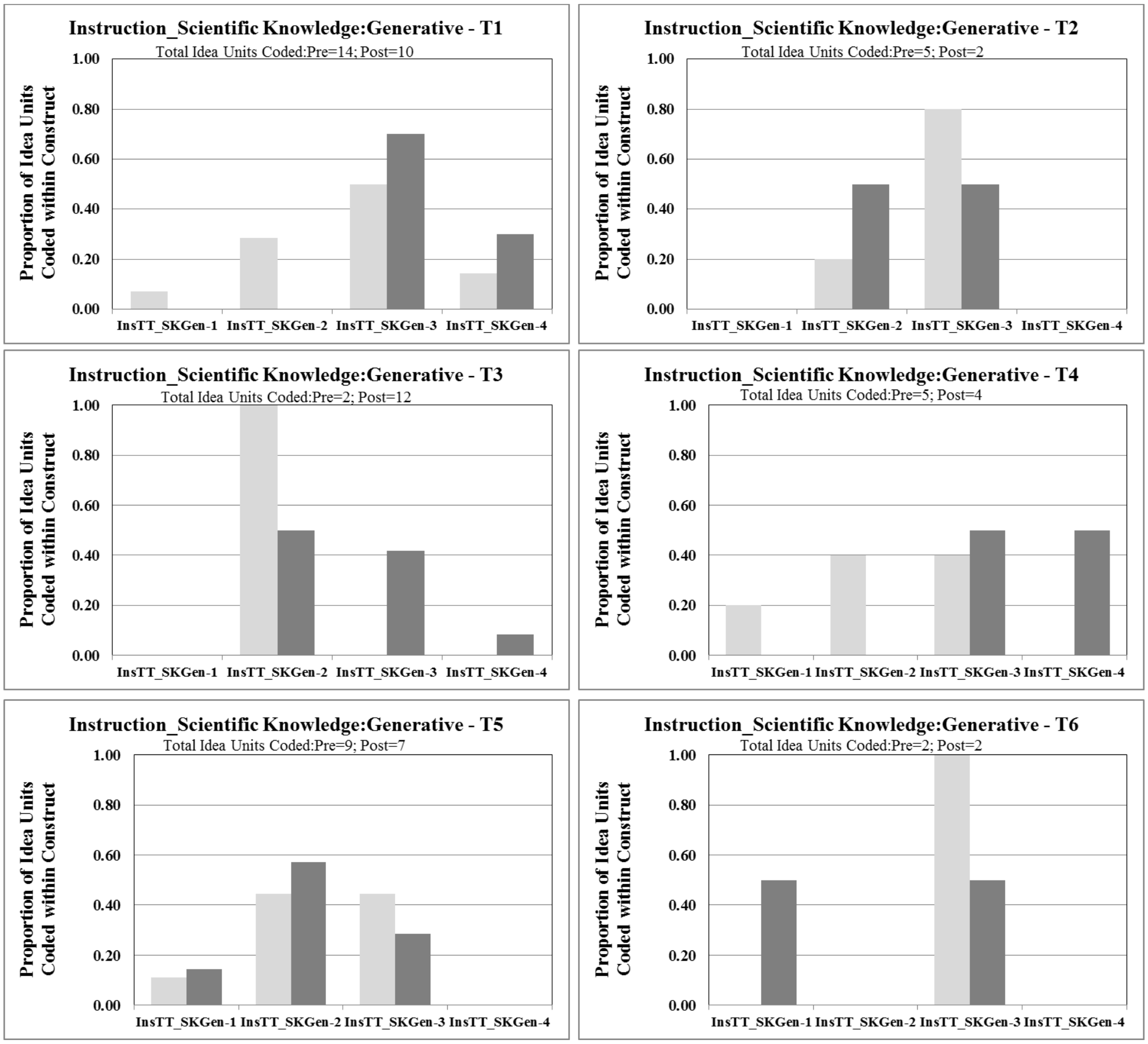


Figure 11. Proportion of idea units coded at each level of InsTT_Scientific Knowledge: Generative. Light gray bars represent pre-program data; dark gray represent post-program data.

With respect to the Scientific Knowledge: Generative construct, study participants T1 and T4 both showed positive change across pre- to post-program measures. This is notable given that both of these teachers seemed more able to convey awareness of and resistance against the prevailing emphasis on verification-based activities found in science curricula following their research experiences. It is interesting to note that neither of these teachers showed corresponding change in pre/post NOS measures as, like all study participants they began with and maintained high levels of understanding of this construct. Therefore, teachers' understanding of this construct in relation to NOS need not have changed in order for them to be able to communicate more sophisticated ideas about how to develop student understanding about the generative nature of scientific knowledge. However, high levels of understanding of this NOS construct does not ensure sophisticated notions of how to reflect this in the classroom, as T6's ideas about this actually decreased in sophistication across pre/post measures. It is therefore possible that her research experience highlighted aspects this construct that she viewed as being incompatible with classroom science instruction (e.g., the amount of time needed to carry out thorough investigations designed to generate new knowledge). Overall, then, although *all* study participants exhibited high levels of understanding of this construct when discussing NOS on both pre- and post-program measures, this level of sophistication generally did not carry into their discussion of classroom instruction.

Scientific knowledge: Co-constructed. The means by which scientific knowledge is constructed through interactions among scientists is described by the Scientific Knowledge: Co-constructed construct. Teachers with more sophisticated understandings of how this might be communicated through instruction would emphasize the importance of students understanding the manner in which scientists co-construct knowledge by drawing upon the expertise of one another in order to describe the natural world. These individuals would also be able to describe specific plans for students to construct classroom-level understanding of course material through the exchange of expertise among students. Those teachers who have less refined understanding of this construct would convey a reliance upon instruction aimed at transmitting knowledge to their students through teacher-driven instruction such as lectures, thereby excluding opportunities for students to work together to develop their own understanding of science content. The levels of differing understanding of this construct in relation to classroom instruction are described in Table 18.

Table 18

Summary of InstructionTeacherTalk_Scientific Knowledge: Co-constructed Codes

Construct	**Code Level (decreasing sophistication)**	**Code Summary**
Scientific Knowledge: Co-constructed	InsTT_SKCo-4	Teacher emphasizes that students should understand that scientific knowledge is built through the co-construction of knowledge among researchers, which requires that they draw upon the expertise of others in order to generate thorough descriptions of the natural world. Teacher discusses plans for students to co-construct a classroom-level understanding of concepts through development and exchange of expertise among students.
	InsTT_SKCo-3	Teacher emphasizes that students should understand that scientific knowledge is built through the co-construction of knowledge among researchers. Teacher discusses potential benefits of building classroom-level understanding of concepts by asking students to work together to do so, but does not describe specific plans for doing so.
	InsTT_SKCo-2	Teacher makes reference to the fact that students should understand that researchers may draw upon the knowledge of others in some way, but fails to make clear the role of this collaboration for the generation of new scientific understanding. Teacher discusses general benefits of student-centered instruction (e.g., students working together to help generate ideas or discuss a concept), but does not emphasize how this might help them develop conceptual understanding of a topic.
	InsTT_SKCo-1	Teacher fails to emphasize any ways in which scientific knowledge is built through the co-construction of knowledge among researchers. Teacher focuses on imparting knowledge to students through teacher-driven instruction.

Pre/post comparisons of talk related to the co-constructed nature of scientific knowledge. Of study participants, only T1 showed shifts in the sophistication of his thinking about instruction related to this construct. These changes are depicted in Figure 12.

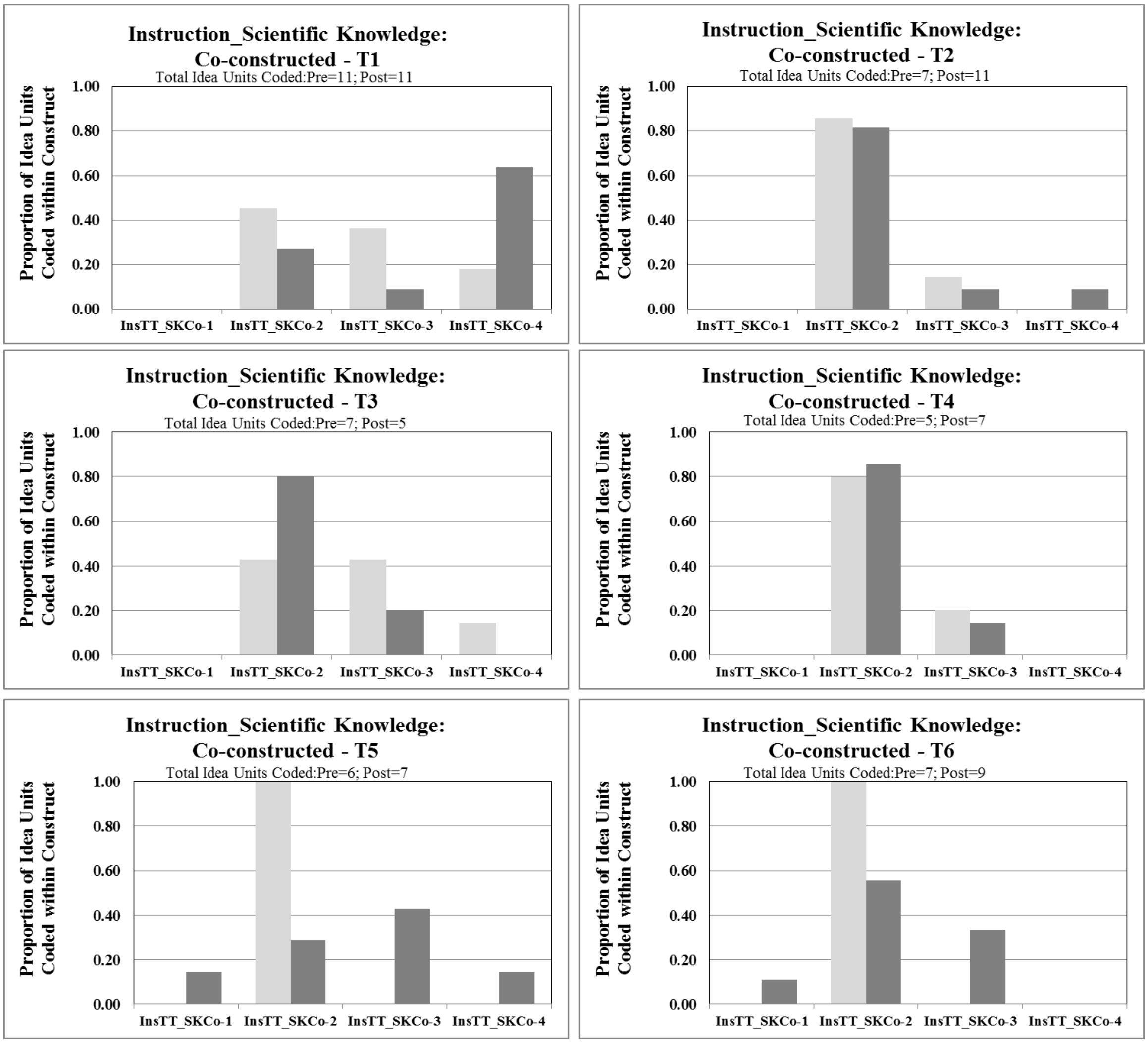


Figure 12. Proportion of idea units coded at each level of InsTT_Scientific Knowledge: Co-constructed. Light gray bars represent pre-program data; dark gray represent post-program data.

One aspect of the changes seen in the responses of T1 is particularly worth noting. Like all study participants, T1 still communicated some idea units that were considered less-sophisticated in his post-program *Instructional Interviews*. Therefore, although he did show an overall shift toward more sophisticated thinking about this construct in relation to instruction, some lower-level thinking persisted. Another interesting aspect of the results for this construct is the lack of change for all other study participants, despite variations in the extent and direction of change in their discussion of this aspect of NOS absent of the instructional context. In the case of T6, for instance, these results suggest she was able to think more effectively about this construct when considering their own understanding of this construct following participation in research, yet was not able to import this into her thinking about the classroom. These variations indicate that research experiences help make this construct salient to teachers in different ways. While some experiences may highlight the co-construction of knowledge strictly in the context of NOS, others may help teachers think in more sophisticated ways about how this construct can be related to classroom instruction.

Modeling and inscribing: Types of models. This construct asserts the central role of modeling in the work of scientists and emphasizes how different types of models are generated and used to explain natural phenomena. Teachers with a sophisticated appreciation of the importance of modeling would describe the need to provide opportunities for students to learn about, develop, and use a variety of models in ways that parallel their use by science researchers. They would also engage them in modeling practices in ways that emphasize how models reduce phenomena to more interpretable forms while simultaneously amplifying certain aspects of the phenomenon to increase its broader applicability. In contrast, teachers who lack understanding of this construct would fail to convey intent to help students understand the role of modeling in the scientific community and the types of models employed by researchers. Table 19 summarizes these two extremes, as well as the other levels of understanding identified for this construct in relation to instruction.

Table 19

Summary of InstructionTeacherTalk_Modeling Codes

Construct	**Code Level (decreasing sophistication)**	**Code Summary**
Modeling & Inscribing: Types of Models	InsTT_Mod-4	Teacher explains that students should understand the central role of modeling in science as a means to understand and natural world by reducing the phenomenon to a more interpretable form, while simultaneously amplifying it in terms of its applicability to other, related phenomena. Teacher stresses importance of providing students with opportunities to develop and use a variety of models to help them understand its central role in scientific research, as well as course content, and describes specific plans to do so.
	InsTT_Mod-3	Teacher explains that students should understand some of the types of models employed in scientific research and the ways in which they are used to advance understanding of the natural world by representing a phenomenon in an interpretable form. Teacher talks about how creating or interacting with a variety of different types of models may help students better understand certain concepts.
	InsTT_Mod-2	Teacher explains that students should understand how a certain type of model is used in scientific research. Teacher talks about the ways in which creating or interacting with a particular type of model, such as a structural model, can help students visualize a concept.
	InsTT_Mod-1	Teacher does not explain a need for students to understand the use of modeling in scientific disciplines, nor any ways in which creating or interacting with models might be useful for classroom instruction.

Pre/post comparisons of talk related to the role of modeling. Figure 13 illustrates shifts in participants' thinking about the modeling construct in relation to classroom instruction.

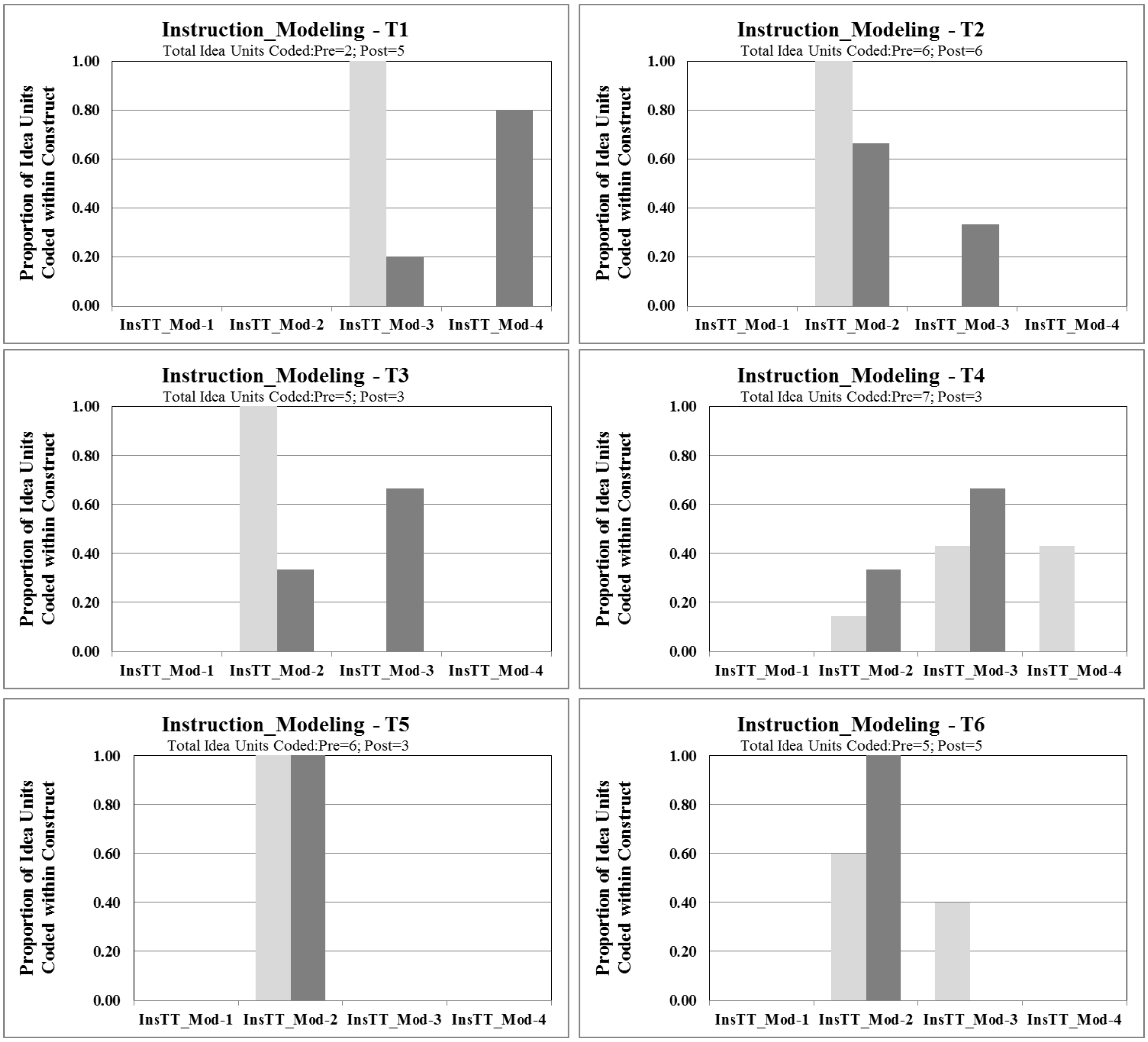


Figure 13. Proportion of idea units coded at each level of InsTT_Modeling. Light gray bars represent pre-program data; dark gray represent post-program data.

Of all study participants, only T4 exhibited change in his thinking about instruction related to the modeling construct, and this change reflected a decrease in the sophistication of this thinking. This is rather alarming given that he maintained high levels of understanding of the role of modeling in pre/post NOS measures, and even more so in light of the fact that his project focused on designing a device to be used in an educational setting to help model aspects of system dynamics. It is possible, though, that his focus on engineering design for the classroom may have effectively narrowed the ways in which he thought about using models for instruction.

For those who did not show overall change in their thinking relative to this construct, some participants are nevertheless worth further consideration, specifically T1, T3, and T5. While T1 communicated relatively sophisticated ideas in the pre-program *Instructional Interview*, this improved following participation in research as evidenced by the fact that the highest-level code was assigned to a greater proportion of his responses in his post-program interview. With respect to T3, there was an increase in the proportion of idea units assigned to higher-level codes, as well as decreases in those coded to lower-level codes. It is interesting to note that T3 also exhibited change in his level of understanding when discussing this construct in pre/post NOS measures. This shift may have contributed to the increasing level of sophistication of his idea units related to modeling and classroom instruction

Yet another interesting case is seen in T5, who increased in the level of sophistication of the ideas he communicated about modeling across pre/post program NOS measures, but exhibited no change in his talk about modeling and instruction. The conflicting outcomes for T1, T3, T4, and and T5, then, suggest that ideas about this focal construct may be taken up differently by different teachers, and that change in one aspect (i.e., NOS understanding or ideas about instruction related to NOS) does not guarantee corresponding change in the other.

Historical and contemporary context: Beliefs and values. This final construct emphasizes that societal and personal beliefs influence the types of research questions and methodologies pursued (and even supported through funding, etc.) in science.

Teachers who possess more sophisticated ideas about how this aspect of NOS could be connected to classroom practice would convey the importance of helping students understand these influences on the scientific community of practice, as well as describe plans for engaging students in the consideration of such influences. A teacher's emphasis on the objectivity of scientific work and lack of desire to engage students in the consideration of societal or personal influences on science would indicate low levels of sophistication in thinking about classroom instruction related to this construct. These two levels, as well as those that fall between these extremes, are summarized in Table 20.

Table 20

Summary of InstructionTeacherTalk_Context:Beliefs and Values Codes

Construct	**Code Level (decreasing sophistication)**	**Code Summary**
Historical & Contemporary Context: Beliefs & Values	InsTT_CB&V-4	Teacher discusses the importance of students recognizing ways in which societal and personal beliefs and values influence the types of research pursued in science and the extent to which these values may impact the types of questions pursued and/or the funding available for particular research questions. Teacher describes specific plans for asking students to consider how the beliefs and values of society and scientists may influence the types of questions pursued and methodologies used in research.
	InsTT_CB&V-3	Teacher discusses the importance of students recognizing the ways in which societal and personal beliefs and values influence the types of research pursued in science. Teacher expresses desire for students to consider how the beliefs and values of society and scientists may influence the types of questions pursued and methodologies used in research, but does not describe any specific plans for doing so.
	InsTT_CB&V-2	Teacher discusses the importance of students viewing science as objective, but also talks about asking them to consider some influences on the types of research that is valued. Teacher expresses desire for students to consider how the beliefs and values of either society or scientists may influence the type of questions pursued in research, but does not describe any specific plans for doing so.
	InsTT_CB&V-1	Teacher discusses the importance of students understanding science as remaining objective and immune to any personal or societal influence. Teacher emphasizes need for students to work objectively and not allow their own beliefs or values to influence their work.

Pre/post comparisons of talk related to the role of beliefs and values in science research. Pre- to post-program changes in study participants' understanding of instruction related to this construct as communicated through *Instructional Interviews* are shown in Figure 14.

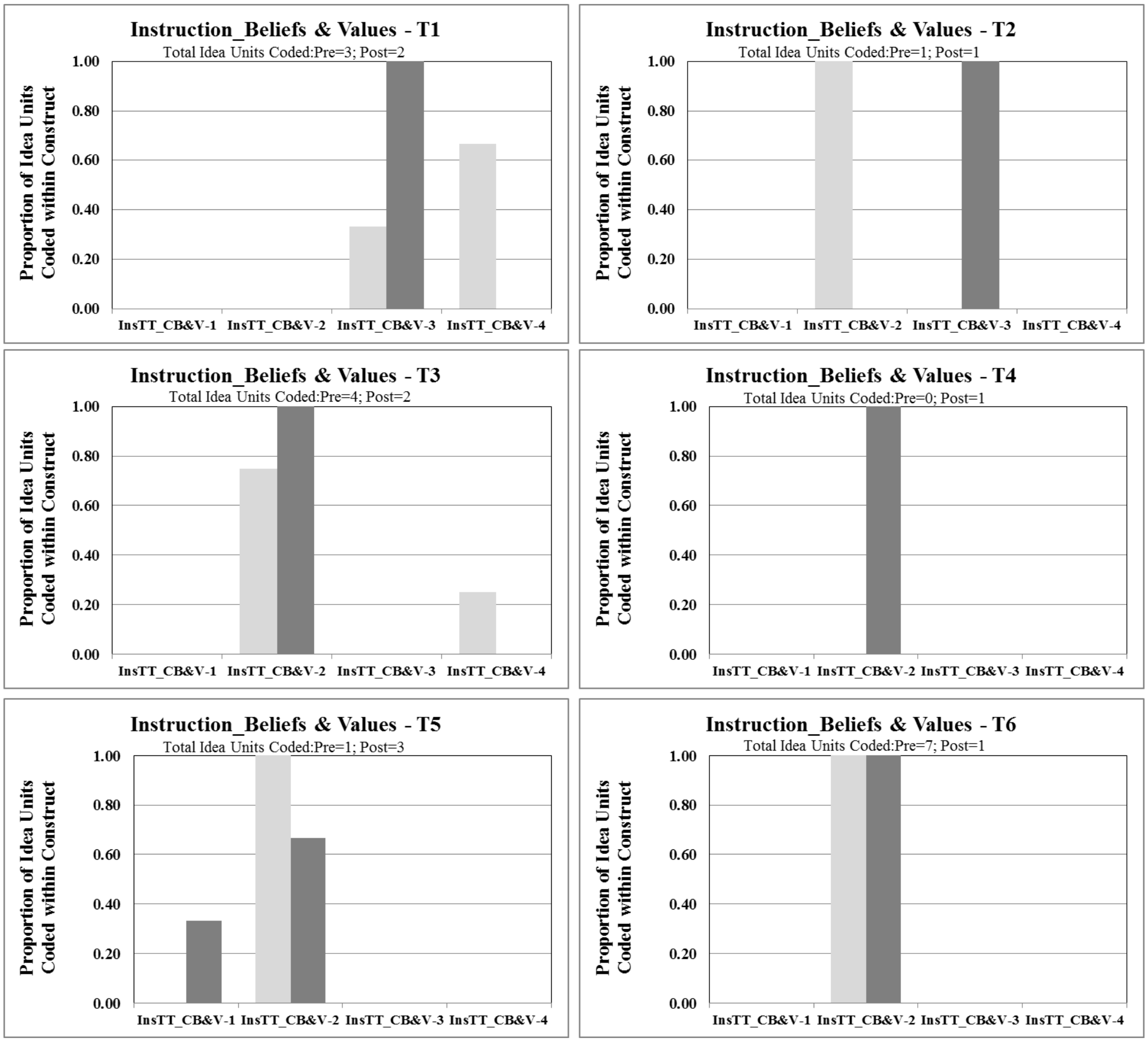


Figure 14. Proportion of idea units coded at each level of InsTT_Context: Beliefs and Values. Light gray bars represent pre-program data; dark gray represent post-program data.

When considering how this construct might be related to or incorporated into classroom instruction, two teachers, T2 and T4, showed positive change in the sophistication of the ideas that they communicated. Like some other constructs (e.g., Scientific Knowledge: Generative, Modeling), these shifts were not universally aligned with corresponding change in NOS understanding. That is, T2 exhibited change with respect to both NOS understanding of this construct and instruction related to this construct, while T4 showed no change in NOS understanding related to this construct (due to his high level of understanding in both pre- and post-program measures) yet still increased in the sophistication with which he related this construct to classroom instruction. In the case of T2, this increase could have been due in part to her ability to see connections of her project to real-world applications, as well as direct links to her course content (i.e., a unit on bones in her Anatomy and Physiology classes). This may have facilitated her thinking about how to bring this aspect of NOS into the classroom.

In addition to these inconsistencies, one study participant, T5, maintained mid-range understanding of the influence of societal and personal beliefs and values when only discussing NOS, yet showed a decrease in the sophistication of his talk about this construct in relation to instruction. It is therefore evident that increased understanding of this construct in relation to NOS does not guarantee, yet also does not preclude, translation into thinking about teaching practice.

Summary of teachers' changes in talk about instruction related to NOS. As with the results reported in relation to NOS understanding, Table 21 summarizes changes in the sophistication of participating teachers' thinking about each focal construct in the context of instruction.

Table 21

Summary of Changes in Teachers' Understanding of NOS Constructs in Relation to Instruction

Teacher ID	**Construct**					
	Intellectual Interdependence	Variability of Methodology	Scientific Knowledge: *Generative*	Scientific Knowledge: *Co-Constructed*	Modeling & Inscribing: *Types of Models*	Historical & Contemporary Context: *Beliefs & Values*
T1	M ↑ H	H ↔ H	M ↑ H	M ↑ H	H ↔ H	H ↔ H
T2	L ↑ M	M ↔ M	M ↔ M	M ↔ M	M ↔ M	M ↑ H
T3	M ↔ M	M ↔ M	M ↔ M	M ↔ M	M ↔ M	M ↔ M
T4	L ↑ M	M ↔ M	M ↑ H	M ↔ M	H ↓ M	L ↑ M
T5	L ↔ L	M ↔ M	M ↔ M	M ↔ M	M ↔ M	M ↓ L
T6	M ↓ L	M ↔ M	H ↓ M	M ↔ M	M ↔ M	M ↔ M

Letters to the left of each arrow indicate participant understanding prior to program participation. Letters to the right of each arrow indicate post-program understanding. L reflects low levels of understanding, M reflects medium levels of understanding, and H indicates high levels of understanding. Arrow directionality indicates the direction of change (none, increase, or decrease).

Two study participants are particularly interesting when considering Table 21. The first of these is T6. While she primarily exhibited no change in her talk about the focal NOS constructs in relation to instruction across pre- to post-program measures, *decreases* in her level of sophistication of talk were reflected for two focal constructs. This change in a negative direction occurred despite the shifts that were apparent in her NOS understanding related to three constructs: Intellectual Interdependence, Scientific Knowledge: Co-constructed, and Modeling. This pattern, highlighted through comparison of summary tables 14 and 21, underscores what has already been stated in terms of connections between NOS understanding and thinking about NOS-related instruction. That is, changes in the sophistication of teachers' conceptions of NOS do not ensure that these newly-developed understandings will be generalized to and subsequently carried into their teaching practice.

The other notable case when looking at these results is T1, who exhibited a very different pattern than T6. T1 showed change across three out of six focal constructs (i.e., Intellectual Interdependence, Scientific Knowledge: Generative, and Scientific Knowledge: Co-constructed) when discussing them in relation to classroom instruction. His results for NOS measures, however, reflected that that he did not exhibit meaningful change for any construct due to his high level of pre-existing understanding, therefore there was little room for refinement of his thinking about the focal constructs when discussing NOS in isolation. In contrast, his change across three constructs when discussing them in relation to instruction may indicate that T1's research experience primarily served to strengthen his thinking about how to incorporate different aspects of NOS into his classroom instruction. This suggests that, for teachers who possess sophisticated conceptions of NOS, participation in research may provide a context for them to think about the importance of students developing comparable levels of NOS understanding. This could be due to their research experience highlighting ways in which school science traditionally misrepresents how scientists go about their work, which would be more readily visible to those who maintain more sophisticated notions of NOS prior to engaging in research.

In contrast, for those who do not possess sophisticated conceptions of NOS before participating in research, these results may suggest that it is difficult to develop more sophisticated NOS understandings and consider how NOS prescribes changes in teaching simultaneously. It may well be that the learning of the second works best if it follows from thoughtful consideration of the first. The requirement for RET program participants to develop curriculum units based upon their research experience may have provided a context for such teachers to begin to reflect upon these incongruities between professional science and school science, but more focused attention to these discrepancies may help move teachers' thinking beyond just content-based connections between their research experience and the classroom. Given these differences in the ways teachers' NOS understanding and thinking about instruction related to NOS changed across study participants, it is next important to explore how these shifts may have been reflected in teachers' classroom instruction.

Pre- and Post-program Comparisons: Instructional Observations

As noted previously, pre- and post-program observations of teachers' classroom instruction were made to explore the types of instruction typically enacted by study participants. Unfortunately, due to the timing of pre-program observations for T3 and T5, these observations for both teachers took place during exam review sessions and therefore the instruction observed was atypical. Of the remaining study participants, two contrasting cases best exemplify differences in the extent to which changing conceptions of NOS were reflected in classroom instruction. As previously noted, these two teachers, T1 and T6, showed noticeable differences in the ways in which their understanding of NOS and thinking about instruction related to focal constructs changed following participation in research. Recall that T6 exhibited pre/post shifts toward more sophisticated NOS understanding that were not carried into her discussion of instruction related to NOS. In contrast, T1's relatively high level of NOS understanding prior to participation in research prevented visible change in this understanding. Change was evident, however, in his discussion of instruction related to NOS across several focal constructs. Descriptions of the teaching of these two contrasting cases discerned through *Instructional Observations* follow in order to highlight how these differences in their thinking about NOS and instruction were or were not carried into the classroom.

The classroom observations of T6's instruction prior to and following her participation in research revealed instruction consisting largely of teacher-led lecture using PowerPoint as a platform for conveying information. Although the class was intermittently engaged in discussion during these lectures, this was mostly used to review concepts addressed during a previous class. During post-program observations students did participate in some small-group lab activities aimed at knowledge verification, or asking them to dissect a sheep's brain, which was intended to serve as a model for the human brain, but these activities were very regimented in their procedures.

One notable departure in relation to T6's instruction was that, in her *Instructional Interviews,* T6 described a lab activity she had previously used in an ecology class that was quite unlike what was observed in her lessons. In this activity, students were required to run a series of tests on water samples they obtained from a local river and then assess the water quality of the river. Although students were still following fairly scripted procedures in terms of how to conduct the water quality tests, the results were not pre-determined. This type of activity may have therefore provided an opportunity to communicate ideas about the generative nature of scientific knowledge development. Across all *Instructional Observations*, though, this type of less-structured investigation was lacking, and it became apparent through her *Instructional Interview* that this was an approach that she rarely employed. Therefore, overall, very little instruction was observed that reflected the changes in T6's NOS understanding that were visible in pre/post NOS data. This is perhaps not surprising, though, given that she exhibited no change in the ways that she thought about NOS-related instruction across pre/post measures.

Much of T1's instruction similarly focused on teacher-led lectures, but these lectures regularly incorporated whole-class discussion of lecture content and teacher-led demonstrations with student involvement. Lab activities, although aimed at producing expected results following a procedure provided by the teacher, were consistently integrated into instruction. (It is important to note, however, that, in his pre- and post-program *Instructional Interviews,* T1 described a final exam lab activity that he uses in which he asks students to work in groups to develop their own procedures to investigate an assigned topic based on their prior lab experiences in the class. Although students are still working toward a pre-determined answer, T1 emphasized that importance was placed primarily on the development, recording and, if necessary, revision of their investigation procedures during exam completion.) *Instructional Observations* revealed that these approaches were primarily typical of T1's instruction in his physics and AP physics courses.

In contrast, T1's engineering classes that were observed both prior to and following participation in the RET program focused more on development of models. During pre-program observations, students developed structural models of different styles of bridges using K'NEX building sets. While the K'NEX sets provided some guidance in model construction, students were encouraged to modify the design in order to increase bridge strength and utility. Post-program observations of T1's regular instruction in his engineering class focused on construction of a wind tunnel that would be used for testing model cars and trucks, for which small groups were responsible for the construction of different parts of the tunnel. Overall, students were provided with substantial latitude in terms of their approaches to these two design projects while T1 served as a guide in their development.

Regardless of class, most of T1's instructional time was devoted to student group work rather than teacher-led activity in both pre- and post-program observations. Although the labs observed in his physics classes were aimed primarily at knowledge verification through the completion of a predetermined procedure, which misrepresents the generative nature of scientific knowledge and variability of methodology in science, the final exam activity described by T1 would allow greater methodological flexibility, thereby conveying a more accurate version of the variability that exists in approaches to scientific research in the classroom. The role of this variability of methods was also reflected in the autonomy granted to students in their model development in T1's engineering classes. Furthermore, the means by which students worked together during lab activities, particularly as they developed expertise about the construction of different parts of the wind tunnel and then consolidated their products for its assembly, may help convey to students the ways in which scientists collaborate in order to pursue a common goal by working together to build upon each other's knowledge.

Like T6, few differences were seen in T1's regular classroom instruction during pre- and post-program *Instructional Observations*. Therefore, the changes that occurred in the ways in which he discussed NOS in relation to classroom instruction were not clearly reflected in this instruction, suggesting that, although T1 could voice more sophisticated ideas about NOS instruction in his *Instructional Interview*, he was unable to translate this new understanding into regular classroom practice effectively. The influence of this shifting understanding becomes more visible, however, through his instruction during his research experience-based curriculum unit, which is next described.

A closer look at post-program instruction: regular versus module-based. In addition to observations of teacher' regular classroom instruction, post-program observations were also conducted to document teaching during their research experience-based curriculum module. Although not a stated goal of the RET program guidelines for module development, this instruction was believed to have provided the richest opportunity for teachers to communicate more sophisticated conceptions of NOS to their students both explicitly and implicitly. While study participants' teaching took on the Legacy Cycle approach to instruction for these units in terms of how they framed the content to be addressed, more often than not their instructional strategies closely resembled their regular classroom instruction. That is, although they introduced the unit of study by posing a challenge question to students and concluded it by requiring them to produce and present some type of product, the instruction used to move them through the other parts of the Legacy Cycle were not unlike their typical instruction. This is not intended as a criticism of this approach to instruction, as it does allow for methodological flexibility in teaching within its framework and is not designed nor intended to enhance NOS instruction specifically, but instead is meant to highlight that most teachers were incapable of incorporating any more sophisticated notions of NOS even given this contextualized, problem-based approach to instruction.

One exception to these observations was T1, who implemented his curriculum module in his Engineering classes. Although much of his regular classroom instruction focused on labs and model-building and he, unlike other study participants, required that students draw upon each other's knowledge for the achievement of a common goal (i.e., through construction of the wind tunnel), T1's instruction during his research-based curriculum asked students to do this to an even greater extent. As their challenge, T1 asked students to work in groups to develop a museum exhibit explaining and demonstrating computer-guided surgery in the brain intended to alleviate the symptoms of Parkinson's disease. Throughout the course of this curriculum unit, which spanned several weeks in length, students first worked in small groups to research different aspects of the disease, surgery, and related medical imaging and then shared their expertise with the other groups in the class. The students then met in new groups to develop models and other exhibit materials that would explain the surgery to museum patrons. T1 orchestrated opportunities for these groups to collaborate with one another, both informally and through structured roundtable discussions, and draw upon their developing knowledge in order to ensure accuracy and efficacy of the materials that they were developing.

Of all instruction observed throughout this study, this research experience-based curriculum communicated the most sophisticated conceptions of NOS to students, both implicitly and explicitly. Students engaged with this unit of study were asked to develop understanding of different science disciplines (e.g., anatomy, physics) and then draw upon the expertise of others in these different disciplines in order to achieve a common goal, thereby highlighting the Intellectual Exchange and Co-construction of Knowledge within the scientific community of practice. In addition, students were interacting with and generating different types of models (e.g., structural models of surgical procedures, computer-based models of brain structure and working with computer code for manipulating these models) that emphasized some of the different ways in which scientists engage in modeling as they conduct their research. The relative freedom that students had in terms of their methods for developing and working with their models (within the constraints of available materials) also provides some insight into variability of methodology in science. Finally, the challenge itself centered on a disease which receives considerable attention from society (i.e., Parkinson's) and for which research is prioritized. This may help illustrate the ways in which societal beliefs and values influence the types of research that is supported and conducted.

Although this curriculum clearly provided a rich context for discussion and/or exploration of most of the focal NOS constructs, there were some that may not have been adequately conveyed or made salient. Most notably, little opportunity existed for students to develop an understanding of the generative nature of scientific knowledge development, despite T1's pre/post gains in the sophistication of his talk about instruction related to this construct. Students were asked to research and learn about existing approaches to Parkinson's treatment rather than consider or develop new approaches. Although this would extend beyond the goals of the curriculum unit, researching scientists would likely focus on that type of generative work. Despite this shortcoming, this curriculum module provided a solid framework for helping build students' understanding of NOS. It therefore appears that, although T1 showed change in terms of his sophistication of thinking about instruction related to NOS, he was most effectively able to translate these changes into classroom instruction when that instruction was tied to his own research experience. Implications of this, as well as other study results, are explored in Chapter V.

CHAPTER V

DISCUSSION

A review of the results described above reveals that research experiences can have a range of impacts on teachers' NOS understanding and their thinking about instruction related to NOS. Although only a few patterns could be identified in these shifts, it is important to consider potential constraints and affordances of an engineering-based research experience, as well as implications of this study for teacher professional development and pre-service teacher education.

Teachers' Research Experiences, NOS Understanding, and NOS Instruction

As noted previously, the lab contexts in which teachers worked, the scope of the projects for which they were responsible, and the specific activities and interpersonal interactions in which they engaged as part of their research experience varied widely across participants. These differences all have implications with respect to teachers' NOS understanding and their thinking about instruction related to NOS based on the theoretical underpinnings of this study. That is, how might Lave and Wenger's (1991) work on situated learning through legitimate peripheral participation, intent participation as described by Rogoff et al. (2003), and Goodwin's (1994) lens of professional vision provide insight into the results of this study? Each of these is discussed below in relation to teachers' research experiences, as well as changes in their NOS understanding and thinking about NOS-related instruction.

Legitimate Peripheral Participation, Intent Participation, and Professional Vision

Legitimate peripheral participation and intent participation. As described previously, the perspective of situated learning through legitimate peripheral participation put forth by Lave and Wenger (1991) might suggest that teachers who were more effectively able to progress from newcomers to relatively-experienced old-timers within the scientific community of practice would acquire a deeper understanding of the enterprise of science. This could, in turn, enable them to act as the relative old-timers within their own classrooms in order to help facilitate the development of students' NOS understanding.

To some extent, this perspective does shed light upon why such variability was evident in teachers' pre/post changes in NOS understanding, as they participated in vastly different research activities in a range of roles. For instance, considering the potential relevancy of legitimate peripheral participation for research settings, is not surprising that T4 did not exhibit much change in his NOS understanding related to five out of six focal constructs, given that his project did not directly contribute to the advancement of his lab's broader research agenda. He therefore remained more of a peripheral participant in his lab throughout his research experience, even working primarily in a room separate from the rest of the lab. While he did develop knowledge of the computer-based programs with which other members of the lab worked, he did so without being able to connect this knowledge to a larger purpose. Furthermore, although T4 attended weekly lab meetings, as well as a larger multi-lab meeting, the lack of connection between his project and the other projects being discussed may have also prevented him from fully engaging in research as an old-timer.

In contrast, the experiences of teachers who worked more integrally with other lab members during their time in the lab are illuminated through the lens of intent participation described by Rogoff et al. (2003). These teachers, such as T2 and T6, who worked side-by-side with graduate student researchers, may have had more opportunities to engage in learning through intent participation, as they constantly interacted with more-expert individuals while working on their projects. In contrast, study participants such as T1 and T4, who worked more independently, may have missed out on such learning opportunities to some extent, leading them to exhibit lesser amounts of pre/post change in NOS understanding. It is also interesting to note that T3, who worked with graduate students in a manner similar to T2 and T6, also exhibited little pre/post change with respect to NOS understanding. Therefore, it appears that engagement in research through legitimate peripheral participation or intent participation is not sufficient for building NOS understanding in relation to the focal NOS constructs.

Professional vision. All teachers experienced some degree of exposure to the professional vision possessed by practicing scientists. It is interesting to consider, though, the different types of professional visions they may have encountered through interactions with different types of individuals during their research experiences and the potential impacts of these varied viewpoints. For instance, might participants such as T1, who primarily interacted with a PI and other established university researchers, have been exposed to different visions of science when compared with T5, who experienced only minimal interactions with the PI and mainly worked with graduate students? Unfortunately this would require insight into the professional visions maintained by these individuals, and this study did not provide these data.

Overall, however, one might expect that a professional vision more closely aligned with that of a practicing scientist (rather than a teacher of science) would be reflected as more sophisticated NOS understanding. The high degree of variability of shifts in study participants' conceptions of NOS indicates that their professional vision became more like that of a practicing scientist with respect to some focal NOS constructs, but certainly not all. With respect to the Intellectual Interdependence of the scientific community of practice, for example, the labs in which participants worked seemed to provide a fertile ground for cultivating a professional vision more like that of a scientists, perhaps due in large part to the interdisciplinary research being conducted.

Given these potential shifts in study participants' professional vision of NOS from that of a teacher of science to practitioner of science, it is next important to consider the implications these changes in their thinking about instruction related to NOS and their enacted classroom instruction. It is interesting to consider whether the development of a professional vision more closely aligned with that of scientists might actually impede a teacher's ability to make connections between their newly-developed NOS understanding and instruction related to NOS. That is, might they become too entrenched in the professional vision of scientists to be able to consider how to translate their experiences into the classroom most effectively? This may have been the case for T6, who exhibited pre/post shifts in terms of her sophistication of NOS understanding but did not reflect any positive changes in her talk about NOS-related instruction. In contrast, T1, who worked with more autonomy throughout his research experience, showed little change in NOS understanding due to his advanced pre-existing understanding, but was able to talk with greater levels of sophistication about instruction related to NOS. It is therefore possible that he had more opportunities to think about connections between his research experience (beyond just the development of his curriculum module) since his attention was not constantly being directed by others (i.e., graduate students) monitoring his work. How, then, might we more effectively engage teachers in research experiences that improve both their NOS understanding and their instruction related to NOS? I conclude this discussion by considering this question.

Implications for Design of Research Experience-Based Professional Development and Pre-Service Teacher Education

Despite the NOS framework that I developed and employed here being designed to be a more authentic, generalizable depiction of scientific practice, it is apparent that participation in research in engineering-based settings is not adequate for developing more sophisticated conceptions of NOS in relation to all facets of my framework, nor for translating any changes in understanding into classroom practice. We must therefore consider what other supports need to be established to facilitate improved development of NOS understanding and related classroom instruction.

Constraints and Affordances of Engineering-Based Research Settings

One major consideration with respect to the development of NOS understanding in this study was the fact that all participants were engaged in research grounded primarily in engineering rather than (for most) the science disciplines in which they taught. Although these placements provided unique opportunities to work in highly interdisciplinary environments, the relative lack of familiarity with disciplines other than those that they teach may have made it difficult for teachers to make connections among the disciplines in which they worked. Furthermore, the focus of some teachers' projects on engineering design may have prevented them from participating in (or simply not required them to consider) certain aspects of science research, such as the varied research methodologies employed by scientists in different disciplines (e.g., geology or evolutionary biology). It is therefore not surprising that little change was evident in the thinking of study participants with regard to the Variability of Methodology construct. Also, given the applied nature of engineering research, the generative nature of science research may also be obscured. That is, although teachers experienced research aimed at the production of new *applications* of knowledge in these settings, they may view this as distinct from the generation of new knowledge in and of itself.

In contrast, some aspects of scientific research may be made even clearer through exposure to engineering research, such as the Intellectual Interdependence: Intra- and Interdisciplinary Exchange that takes place in such an environment given the range of fields upon which engineers draw in conducting their work. For instance, T6 worked on a project that brought together fields such as polymer science and human anatomy and physiology. Furthermore, the impact of the Historical and Contemporary Context in which such research occurs may also be highlighted, as prevailing societal beliefs and values impact the types of products for which research and development is prioritized. As discussed previously, T1's work related to the treatment of Parkinson's disease and his observation of a surgical procedure utilizing work related to his project may have made salient this aspect of NOS.

Necessary Supports for Professional Development and Pre-Service Teacher Education

Clearly participation in research is not sufficient for the development of more sophisticated NOS understanding and instruction, regardless of the different, specific types of activities and interactions in which an individual engages while conducting research. It is therefore important to consider what other supports are necessary to support such development.

Development of NOS understanding. The findings of this study serve to underscore the importance of engaging teachers, both in-service and pre-service, in focused discussion of NOS, ideally in relation to research experiences, in order to facilitate the development of adequate levels of understanding across all aspects of NOS. Unlike previous studies that relied primarily on self-report about conceptions of NOS, the measures employed here directly demonstrate this need. While engagement in research can aid in certain aspects of understanding and is important for understanding science as something more than the lectures and scripted lab activities that teachers themselves likely experienced, pre- and in-service teachers require assistance in making connections between what they experience while conducting research and different aspects of NOS.

It may also be helpful for teacher researchers to compare their experiences with others participating in research both within the same field and in other fields in order to enhance these connections. For instance, pre-service or in-service teachers who are working in biomedical laboratory settings might be asked to confer with one another to compare their research experiences, then talk with a broader group of teachers participating in very different forms of research (e.g., field-based research, comparative study) to facilitate exploration of different approaches to research. Such focused, targeted discussions would provide them with opportunities not only to learn about the variability of methodology employed across science disciplines, but also to think across disciplines and seek out commonalities in seemingly disparate work. Exploration of the role of informal interactions among teachers participating in research (e.g., during attendance at weekly lunches, as was the case for participants in this study) may also prove informative for understanding how these opportunities may be capitalized upon to help advance teachers' NOS understanding. Further research is clearly needed to explore the most effective methods for helping pre- and in-service teacher develop adequate conceptions of NOS by building upon authentic research experiences.

Translation of NOS understanding into classroom practice. Once pre- or in-service teachers have established more sophisticated NOS understanding, which alone can be challenging, it is important to help them bring this understanding into the classroom. As this study demonstrates through observations of study participants' instruction, even if changes in teachers' conceptions of NOS occur *and* accompanying changes are visible in the ways in which they talk about their instruction and what it conveys to students about NOS, these changes are not necessarily reflected in the classroom. In this study, two factors that appeared important for a teacher's ability to import their NOS understanding into the classroom through changes in their instruction were the teacher's mindset about science instruction and supports that were available to the teacher. With respect to the teacher's mindset, they needed to value student understanding of NOS and consider approaches that they described as potentially useful for helping students to understand NOS as being feasible in their own classrooms. As noted previously, this may be more easily cultivated in those who already possess deeper understandings of NOS, as they may be better able to appreciate how an understanding of NOS could help students think critically about the work that scientists do. If the teacher possessed such beliefs, they also needed the appropriate supports in place for appreciable change to have occurred in the classroom. These supports could include, but are not limited to, material resources (e.g., supplies), curricular flexibility (e.g., lack of constraints imposed by end-of-course tests), and administrative support.

Again, T1 and T6 serve as illustrative, contrasting cases with respect to how NOS understanding was translated into instruction. In this study, T1 was the only participant who was both open to innovating and improving his instruction and also had an abundance of the aforementioned resources available to him (i.e., he worked in a private school with abundant material resources, most of his classes did not require end-of course tests, and his administration supported innovative teaching). In his post-program Instructional Interview, T1 expressed the following:

> When [the students] conduct an experiment, they have to do…two types of experiments. Type one is just where you hand them a procedure, they learn how to follow instructions and fill in the blanks, just so they know how to actually follow instructions, because that’s hard for some kids. But the second type is the more important one where you present a problem to them and they have to determine the relationship… then solve that problem between whatever variables are involved, where they design the procedure, they figure out what equipment they need, they put it together, they test it, and they determine the answers, if

> they're getting any answers at all that make sense…That I… lean toward mostly. (0:01:18, T1 Post-program Instructional Interview)

The ideas conveyed through this response were also visible during classroom observations of T1's teaching, particularly following participation in research. In contrast, T6 was able to identify value in certain activities for helping students understand NOS, but was resistant to incorporating such activities into her own instruction. She also did not appear to feel equipped in terms of supports for changing her approach toward instruction. She stated the following:

> Whether or not scientists think a certain way or not doesn't really affect the way I teach… it should at times, I'm sure it should be more inquiry…but with the amount of topics that we have to cover in, you know, nine months, especially in biology, we don't have time…to do a lot of inquiry. We just have time to get the information on the paper and because they don't study at home necessarily, especially my biology classes…I have to get it all in class. That's only forty-seven minutes a day, and so I do what I can. (0:22:08, T6 Post-program Instructional Interview)

She also went on to state:

> …if you have a topic that has…a variety of different bits of information that you can bring in, I think that…you can get different students teaching each other different things. But when you have some standards for the state that you have to meet…I need to teach that and make sure that they understand that...And so… you go to graduate school, they teach you that it's better for kids to work in pairs and to work in groups and to share and…present, but I've really found that

> through lectures and demos, that’s probably the most effective way to communicate whatever it is. (00:10:03.03, T6 Post-program Instructional Interview)

Like T1, the instruction observed in T6’s classroom was reflective of the ideas communicated through her interview responses. It therefore appears that teachers’ NOS understanding first gets filtered through their lens of what is valuable for students to understand about science as a discipline, and then this thinking is filtered again through the teachers’ mindsets about instruction and the supports available to them before ultimately being reflected (or not) in instruction. In these ways, the potential for translating changes in NOS understanding into classroom instruction was constrained.

The classroom observations conducted as part of this study revealed that designing a curriculum unit based upon teachers’ research experiences may be one avenue of support for implementing such change. However, this study also makes it clear that this alone is not sufficient, as only one study participant’s instruction was qualitatively different during module instruction in comparison to regular classroom instruction. In order to address this concern, these curriculum units should require not only that teachers develop a classroom-appropriate version of the research in which they participated, but also reflect one or more aspects of NOS either in content or organization of instruction. Should this become an overwhelming prospect for teachers, as some of those who participated in this study struggled with module development even without this requirement, other supports need to be developed in order to help teachers think about how to incorporate either implicit or explicit forms of NOS instruction into their classroom. Additional research is needed to determine whether one of these approaches (research experience-based curriculum with specific NOS components versus NOS instruction independent of the research experience-based curriculum) would be more likely to be enacted by teachers and, ultimately, most beneficial for students.

Appendix A

Instructional Interview Protocol: Pre- and Post-program

1. What do you think students should learn about science in their K12 education?

   - Beyond the science content that you teach, are there any larger, thematic ideas that you try to emphasize across your different science classes? Are there any "big ideas" that travel across content areas and emphasize what is shared across the sciences?

2. What would you say has the greatest impact on your methods of teaching and selection of instructional activities and materials (e.g., county or state curriculum, student interests, your interests, etc.)?

3. When teaching science, some teachers prefer to use more structured lab activities, meaning that students are told what research questions to ask about a topic, how to investigate it, what materials to use, what types of information to record and how to record it, and how to interpret the information. Many of the teachers we've met in the classes where we work say that this is a good idea because it tells the students what to do and what it means. What is your opinion about that way of doing science in school?

   - How might these types of activities help students understand how scientists think and do their work? Are there any aspects of how scientists think and do their work that may be misrepresented by these types of activities?
   - Other teachers prefer that students develop their own research questions and then figure out what information to collect to answer their question, as well as how to collect and interpret it. What is your opinion about that way of doing science in school?
     - How might these types of activities help students understand how scientists think and do their work? Are there any aspects of how scientists think and do their work that may be misrepresented by these types of activities?

4. Some types of lab activities are designed for students to obtain particular results as determined by the lab's creator. How might these types of activities help students understand how scientists think and do their work? Are there any aspects of how scientists think and do their work that may be misrepresented by these types of activities?

5. Tell me what you typically do with your science classes that you think helps your students understand science as a discipline, that is, what scientists do, how they think and do their work.

- What types of classroom instruction do you think most helps their understanding? Why?
- Are there kinds of instruction that people typically do in school science that you think may misrepresent how science is done in the professional world? Why?
- *Post-program only:* To what extent has your instruction changed as a result of your participation in scientific research this past summer?
    - Can you please describe these changes?
    - Do you think these changes might better help your students understand science as a discipline, that is, how scientists think and do their work? If so, in what way(s)?

6. I noticed that you (*fill in appropriate activity/activity structure here, e.g., had your students work in groups*) in the lessons that I observed. How did you choose that particular activity (structure)?

- What did you expect students to take away from that activity or activity structure?
- Is there another instructional approach that you considered?
    - If so, why did you choose the activity that you did?

7. In what way do you think the lesson(s) that I have observed might have helped your students understand science as a discipline or what scientists do?

- What, specifically, do you think may have helped their understanding? How do/would you know?
- Why might this be important?

8. Do you use lab or inquiry activities in your instruction? What goal do you have in mind for those activities?

- Can you describe what labs are usually like in your classes? Would you be able to show me an example?

9. *Pre-program only:* I have asked you to bring in a lab or classroom activity that requires that students work in a way that most closely reflects how scientists think and work. Can you please describe the lab/activity to me?

- Why did you choose this particular lab/activity?
- What is it about this lab/activity that you think might help your students understand how scientists think and work?

- Can you think of a way that this lab/activity could be extended or revised to emphasize how scientists think and work?

Post-program only: Last time we talked about teaching I asked you to bring in a lab or classroom activity that requires that students work in a way that most closely reflects how scientists think and work. You chose a lesson that *(fill in brief description of lesson).*

- Would you still choose this particular lab/activity as one that reflects how scientists think and work?
- What is it about this lab/activity that you think might (not) help your students understand how scientists think and work?
- Can you think of a way that this lab/activity could be extended or revised to (further) emphasize how scientists think and work?

10. In what types of classroom activities do you typically require that students collaborate or work together? Are there classroom activities where you require students to collaborate or work together?

- What do you see as the purpose of these collaborations?
- How do you organize them?
- What's your sense of how well they meet the goals you set for them?

11. Are there occasions in your classes where you expect different students to become knowledgeable about or specialize in different topics or different aspects of a topic? Or does everyone always learn the same material?

- If so, how does this work? Who decides about the areas of specialization?
- Do they share their specialized knowledge? With whom? What formats do you find useful for making that happen? What is your purpose for this knowledge sharing?
- Are there topics for which you find this approach more or less useful? Why?
- Do you think this kind of specializing and sharing could help students understand how scientists think and do their work? Why do you feel this way?

12. Do you do any activities to help students think about how models are used in science? If so, please briefly describe them.

- What types of models do students use or create in your classes?
- How is the way models are used or created by students in your classes similar to the way they are created or used by scientists? How is it different?

13. *<u>Post-program only</u>:* To what extent do you feel that your planning and/or instruction have been influenced by your summer research experience?

- In what ways have they been influenced?
- Were there certain aspects of your research experience that you feel may have had a particularly notable influence on the ways that you plan instruction or the types of learning experiences that you plan for your students?

14. *<u>Post-program only</u>:* Have you had any further contact in relation to the work you did this past summer with any members of the lab with whom you worked since the conclusion of the RET program? If so, please briefly describe the frequency/duration, nature (e.g., via e-mail, in person) and overall purpose (e.g., follow-up to your summer work, continuing collaboration with the lab, module development) of this interaction.

- Do you have any other final thoughts or reflections on your research experience?

Appendix B

NOS Questionnaire: Pre- and Post-Program

Pre-program only: Background Information

1. *Demographics*: Please check the appropriate response box for each question below and/or fill in the requested information in the field provided.

-Gender: ☐ Male ☐ Female

-Ethnicity:
☐ African American
☐ Caucasian
☐ Native American
☐ Asian/Pacific Islander
☐ Latina/Latino
☐ Other

-Age:

2. *Education and Professional Training*: Please check the appropriate boxes for *all* degrees that you hold at this time and as necessary indicate the area in which they were obtained.

☐ High School Diploma

☐ Bachelor's Degree

Degree(s) Conferred:

Area(s) of Study:

☐ Master's Degree

Degree(s) Conferred:

Area(s) of Study:

☐ PhD

Area(s) of Study:

☐ Teaching Certification

Content Area(s):

Grade Level(s):

☐ Other

Area(s) of Study:

-If you are currently working toward the completion of a degree, please identify the type of degree and your area(s) of study.

3. *Teaching Experience*: Please check the appropriate response box for each question below and/or fill in the requested information in the field provided.

-Years of teaching experience:

-School type:

☐ Private ☐ Public ☐ Other

☐ Urban ☐ Suburban ☐ Rural ☐ Other

-Grade level(s) taught:

☐ 9 ☐ 10 ☐ 11 ☐ 12

☐ Other

-Subject(s) currently taught:

-Other subjects taught previously:

4. *Prior research experience*: Please describe any prior involvement in scientific research. These experiences may include (but are not limited to) research conducted during prior coursework, independent studies, professional development programs, or industry-based employment.

5. *Other Science Learning*: Other than those described above, have you ever had any other type of science-related learning experience? If yes, please describe this experience.

6. *Extracurricular Activities*: Please briefly describe your hobbies.

Pre-program and Post-program: Views of Science

1. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?

2. What is an experiment?

3. Does the development of scientific knowledge **require** experiments?

- If yes, explain why. Give an example to defend your position.

- If no, explain why. Give an example to defend your position.

4. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change?

- If you believe that scientific theories do not change, explain why. Defend your answer with examples.

- If you believe that scientific theories do change: (a) Explain why theories change? (b) Explain why we bother to learn scientific theories? Defend your answer with examples.

5. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.

6. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence **do you think** scientists used to determine what an atom looks like?

7. Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain are scientists about their characterization of what a species is? What specific evidence **do you think** scientists used to determine what a species is?

8. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The

second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these **different conclusions** possible if scientists in both groups have access to and use the **same set of data** to derive their conclusions?

9. Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced.

- If you believe that science reflects social and cultural values, explain why. Defend your answer with examples.

- If you believe that science is universal, explain why. Defend your answer with examples.

10. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?

- If yes, then at which stages of the investigations you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate.

- If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

Appendix C

NOS Interview Protocol: Pre- and Post-Program

<u>Taken from Ryder, Leach, & Driver (1999)</u>

1. How do scientists decide which questions to investigate?

2. Why do scientists do experiments?

3. How can good scientific work be distinguished from bad scientific work?

4. Why do you think that some scientific work stands the test of time whereas other scientific work is forgotten?

5. How are conflicts of ideas resolved in the scientific community?

<u>Additional Questions</u>

1. *<u>Pre-program only</u>:* What do you expect your research experience to be like?
    - Do you expect that it will change your classroom instruction?
    - If yes, how? If no, why not?

2. *<u>Pre-program only</u>:* How or to what extent do you expect your research experience will help you understand science as a discipline or how scientists think and do their work?
    - Why do you feel this way?

3. What do you see as the primary goals of scientific research?
    - Do these goals differ in different disciplines?
        - If yes, could you please provide an example?
            - Why and in what ways do they differ?

    - If no, why not?

4. Given all the different disciplines within science such as chemistry, biology, physics, etc. (and even more subdisciplines within these) is there anything that is common to *all* of these fields in terms of how scientists think and do their work?

- What about how knowledge is produced or the type of knowledge is produced? Do they have anything in common across disciplines?

5. What do you think are some of the things that influence what types of research are pursued?

6. How would you describe what scientists do?

- How do they go about conducting research?
- How do they come up with the questions that they investigate?
- Do they all follow the same steps when conducting research?
    - If yes, what are these steps? If no, why not?

7. How do you think scientific knowledge is constructed/generated/built?

- Do you think science and scientists strive more to produce new knowledge, to verify existing knowledge, or both? Why do you feel this way?

8. What do you see as the purpose of collaboration in science research? How do you think these collaborations happen or get started? Do you think collaboration is important?

- Why do you think it is important?
    - Are some types of collaboration more important than others? Why or why not?
- Why do you think it is not important?

9. In reference to question 6 of your questionnaire [*show question: Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence* ***do you think*** *scientists used to determine what an atom looks like?*], if scientists are not completely certain about the structure of the atom, what is the purpose of that structural description of what an atom looks like?

- What are the benefits or drawbacks of that description?

10. In what ways are models used in scientific research?

- Do the ways that models are used look different in different disciplines, such as in ecology and physics?
    - If so, why? If not, why not?

11. *Insert other questions asking that participants provide further explanation for or expand upon their responses to the written NOS questionnaire.*

12. *<u>Post-program only</u>:* In what ways do you feel that your research experience met your expectations?

- Why do you feel that way?
- In what ways did it differ from your expectations?

13. *<u>Post-program only</u>:* How or to what extent do you feel that your classroom instruction will change as a result of your participation in a research project?

- Why do you feel that way?
- Do you think it might change more in some classes or subject areas than in others?
    - If so, how might they differ? Why?
    - If not, why not?

14. *<u>Post-program only</u>:* What did you learn about science that you didn't know before participating in your research project?

- Please tell me some ways you plan to incorporate this knowledge into your classroom instruction.
    - Do you think it might change more in some classes or subject areas than in others?
        - If so, how might they differ? Why? If not, why not?

Appendix D

Daily Activity Log

Instructions: Please provide the following information for *each* of your daily activities while working in your lab. Given that you will likely participate in more than one activity each day, please copy and paste the blank form as often as necessary.

Date:

1. Please indicate the *times* at which the activity began and ended:

    -Start time: -End time:

2. Please provide a brief *description of the activity* that took place in this time period.

3. Please describe the *purpose of this activity*.

4. Please describe *your role in this activity*.

5. Please list the *name* and *position* of any other individuals who participated in this activity (e.g., research mentor, graduate student, other RET teacher). Please also identify their *role(s)* in this activity. Please note: if no other individuals were involved in this activity, please write "NA".

    -Name & position:

        -Role(s) in activity:

Appendix E

Weekly Written Reflection

1. What did you do or learn this week that you found particularly helpful, interesting, and/or informative? Please indicate the date and time of the activity and explain why you found it helpful, interesting, and/or informative.

2. What did you do or learn this week that you found particularly unhelpful, uninteresting, and/or uninformative? Please indicate the date and time of the activity and explain why you found it unhelpful, uninteresting, and/or uninformative.

3. What did you do or learn this week that you think helps you understand science as a discipline or how scientists think or do their work? Please indicate the date and time of the activity and explain why you think it helps your understanding.

4. Was there anything that you did or learned this week that you think would be useful for helping your students understand science as a discipline or how scientists think or do their work? If so, please indicate the date and time of the activity and explain why you think it might help your students' understanding.

    - Do you have any ideas about how you might try to incorporate this into your classroom instruction?

Appendix F

Bi-weekly Activity Interview Protocol

1. Tell me about the overall goals of the lab in which you are working.

2. Please give me an overview of your project.
    - -Where are you now in the project?
    - -What are your next steps?
    - -How does your project fit in with the overall goals of your lab's research?

3. *Initial interview only:* Are you getting a sense of the day-to-day activity of the lab? Please describe what that looks like.

    -*Subsequent interviews:* Are you getting a better sense of the day-to-day activity of the lab? Please describe what that looks like.

    - -How typical is your own activity in comparison to that of the other people working in your lab?
        - -To what extent is what you're doing comparable to the everyday experiences of your PI/research mentor?
        - -To what extent is what you're doing comparable to the everyday experiences of the grad student(s) with whom you've been working?

4. *Specific clarification of information contained in activity logs and/or reflections as needed.*

5. What has stood out to you the most (thus far/since we last talked)?
    - -What have you found most useful or helpful for your understanding of science as a discipline, that is, how scientists think and do their work?
    - -Beyond your curricular unit, have you had any thoughts about how you might connect this understanding back to your classroom?
        - -If so, please describe your thinking.

Appendix G

NOS Codes and Sample Responses for Focal Constructs

Focal NOS Construct	Coding Scheme		
	Code Name	**Code Description**	**Sample Response(s)**
Intellectual Interdependence: Intra- and Interdisciplinary Exchange	NOS_II-5	Scientists draw upon the expertise of colleagues within and across science disciplines, both extant and their predecessors, in pursuit of common research goals. Information is shared through a variety of avenues (e.g., personal communications and interactions, publications, conferences, research protocols).	"the fields are blurry. I mean, just, you can walk around, you, the lab I'm in, if you look at the people involved in it, um, no-one in there is a medical person. They're all electrical engineering, computer science, or physicists. That's their background. Yet they are writing software for neurologists and neurosurgeons and they're in the operating room with them. I'm just trying to understand what they're doing so they can take the skills they have and apply it to a different area. So I think that we've, I think when you get out of the basic, this is sort of applied research in that respect, you start merging everything together." (T1, post-program NOS Interview) "Things that people build off of, like maybe someone who cures cancer in the future uses works from three or four other scientists that, that made small breakthroughs earlier but was able to put those together and, and combine them to, to reach a result. " (T3, pre-program NOS interview)
	NOS_II-4	Scientists draw upon the expertise of colleagues within and across science disciplines, both extant and their predecessors, primarily to expedite or streamline the research process. Information is shared through a variety of avenues.	"you know when you look at that you realize lots of things have to work really effectively and efficiently for this to happen. And so, you need collaboration because, you know, um, electrical engineer is not gonna wanna sit down and necessarily spend all their time learning how to use the computer machine devices and how to make that program work. That's why the mechanical engineers are there. So the collaboration lets you do a lot more than you could by yourself." (T1, pre-program NOS interview)

	NOS_II-3	Scientists collaborate with colleagues within the same (or closely related) discipline. Interactions across disciplines are rare and/or are not emphasized. Information is shared primarily through personal interactions. Scientists build upon knowledge previously established by other researchers through books or publications, but the manner in which they do so is not clear.	"If you talk to somebody, like if you're, we're doing polymers and they go and talk to somebody over in Sweden who's doing polymers, but, and then you compare your methods of doing what you're doing. One may be better than the other and then you can start doing your methods a different way and make it quicker." (T3, post-program NOS Interview)
	NOS_II-2	Scientists sometimes draw upon the knowledge of others, but this is not a central part of their disciplinary work. Knowledge of different disciplines may be necessary to think about their work, but no reference to the need for collaboration in order to do so.	"if you're in the research field, um, if there's any other idea that maybe you didn't think about. Um, two heads are always better than one, um, in any aspect of life and I would think that that would help them" (T2, pre-program NOS Interview) "in the lab it's more application of knowledge. So once they've learned basic chemistry and basic the biology, they're applying it to a problem. So in order to know how to solve a problem you have to have good, good background of, of what's going on." (T6, post-program NOS Interview)
	NOS_II-1	Scientists' work is highly specialized and focuses primarily on one particular topic/area of expertise with minimal interdisciplinary connections.	"each scientist has their own little area of expertise" (T3, pre-program NOS Interview)

Variability of Methodology	NOS_VM-4	Scientists use different methodologies most appropriate for answering their particular research questions. Methods may involve experiments, comparative study, etc. Different scientists investigating similar topics/questions might use different approaches to conduct their research. Scientists do not necessarily follow the same sequence of steps portrayed by the scientific method, but instead revisit and revise their research questions and conjectures as needed based on their findings.	"They must pose unique and interesting questions and methods to try and find the answer to their questions to acquire funding. Then during the investigation must be on the lookout for interesting phenomena that might lead to more discoveries or experiments to pursue." (T1, post-program NOS Questionnaire) "Astronomers don't do classical experiments. Um, but you can do a classical experiment, we can put things, manipulate variables, and then watch an outcome, and measure it. Astronomers, geologists, paleontologists in many cases don't do the classic experiment where you can't go out and, like, kick a star and make it explode. So what you have to do is do a survey study. And your experiment there is, I'm gonna look at 500 yellow stars, very similar to our sun, and what I'm assuming is they're all in different stages of their development and I'll be able to collect data off this whole group and out of that I will be able to draw inferences about our sun." (T1, pre-program NOS interview)
	NOS_VM-3	Scientists typically follow the same progression of steps in their research, but the methods employed in each of these steps differ based on discipline and/or research questions.	"I think the basic approach is the same throughout all of 'em. I mean, we're gonna come up with questions and try to answer the questions and it's just a matter of are the questions directly applicable to humans, helpful...or are they directly applicable to increasing our knowledge base. But I think there's a lot of commonal, commonalities between those." (T1, post-program NOS interview) "they're collecting data based on the scientific process also. You have a theory, you look for data, but the data is already, um, the data isn't a lab that you've run. The data is collected out in nature." (T6, pre-program NOS interview)

	NOS_VM-2	Scientists typically follow the same progression of steps in their research, but the specific methods employed in each of these steps differ based on discipline and/or research question. Regardless of discipline or questions pursued, all scientists employ experiments in their research.	"the things that the researchers are doing right now, you know, every one of 'em are conducting some kind of an experiment, um, whether it be mechanical tests on bones or, um, how, um, how thermal testing on a monkey's fingers will, will make its, you know, certain areas of its brain light up. Those are all experiments in my, in my mind, so I would say in every, in every form of this there would have to be some kind of experiment." (T2, pre-program NOS Interview) "maybe a, a biologist and a chemist are faced with, okay, why is the cellular membrane in this particular cell not, um, I don't know, not undergoing active transport, well, then maybe the, the biologist looks at the, the DNA in the cell, and maybe there's a mutation, or the chemist looks at the chemical makeup of the cell membrane itself and tries to figure out, you know, maybe it, it's a chemical component that's disrupted within the membrane...I think that they experiment and follow through with what their, their thesis or their theory was." (T6, post-program NOS Interview)
	NOS_VM-1	Scientists all use the scientific method and experiments when conducting research.	"I think it goes right back to the scientific method. I think that everybody uses it. I think it's all about, here's a problem, create a solution that you have some idea might be the right answer a.k.a. hypothesis, experiment, data, conclusions, start all over again, I think that's very central to all of them. Um, I'm, I'm gonna keep going back to that. I think, I think you have to go across that no matter where you go." (T4, pre-program NOS Interview)

Scientific Knowledge: Generative	NOS_SKGen-4	Scientists primarily strive to generate new knowledge. While they may revisit, verify, and subsequently refine existing knowledge during this process, the driving goal is to produce new understandings of natural phenomena.	"Science is an active process that tests ideas and synthesizes information. Science does not need to rehash already proven concepts unless a new experiment poses a question that seems to require an answer that does not fit with a known concept. At that point, one needs to make sure the new answer was arrived at properly and then begin to test the new idea." (T1, post-program NOS Questionnaire)"discovery; uh, to research and discover new things that can help mankind, I guess. You know, as far as science is concerned, to, or to better something that's already in use." (T5, pre-program NOS Interview)
	NOS_SKGen-3	Scientists strive to both verify existing knowledge and generate new knowledge. There is a fairly even balance between these two goals. Verification is aimed at reiterating existing knowledge in order to improve its validity.	"I would say a lot of it is, is both. Um, you have some people who, you know, who work to, to verify old knowledge, to just, you know make sure that everything's okay. A lot of those, um, like your, your chemist, you know, there's not a whole lot that changes, new knowledge that comes about about chemicals, uh, or about the periodic table. They pretty much know how those are gonna react, so I would say, you know, that, that's kind of just playing off what they already know. Um, new knowledge? You know, look at, medicine changes every day. Um, there's new knowledge about, you know, new medicines and new procedures to do, so I would say that's, you know, that's something that is, that's new knowledge that they try to gain." (T2, post-program NOS Interview)
	NOS_SKGen-2	Scientists primarily strive to verify existing knowledge. New knowledge may be generated during this process, but this is not the intended goal.	"the idea of theory A is here, and theory A says that this experiment should provide this result, so I could validate this theory by performing this experiment and getting the same results as, as they got. I, I could see where that would be useful...but that's not, if you're validating somebody else's work you're not really looking at gaining new knowledge, at that point." (T4, pre-program NOS Interview)

	NOS_SKGen-1	Scientists work to verify existing scientific knowledge in order to improve its validity.	(None available)
Scientific Knowledge: Co-constructed	NOS_SKCo-4	Collaboration among scientists (both among practicing scientists and their predecessors) leads to the building of scientific ideas and refinement of scientific knowledge. This results from scientists drawing upon the expertise of other researchers as they collaborate to construct this advanced scientific knowledge.	"there's this huge depth of knowledge you really need to have in order to make things work. And so you, you may not be able to have it all in one person, so what happens is these collaborations form and pull people from different areas with a common goal because your depth of knowledge now is phenomenal and your breadth of knowledge is immense now. If you put a neurologist, a neurosurgeon, a computer scientist, electrical engineer, and all these people together, you can, you have the ability to do a lot of pretty amazing things. And so, at that point, you now have a really potent team, and that's what's kind of interesting." (T1, post-program NOS Interview) "This is from the Imaging Center. They're collaborating with the Bone Center. You know that's a big collaboration from di, from different centers and different departments, um, to try to, you know, come to a common goal. They don't know a whole lot about bones, but [the researcher with whomT2 worked] does, or [another researcher] does, so I mean it's, it works really well to make sure that you, you know, you go to those people who have the knowledge that you need." (T2, post-program NOS Interview)
	NOS_SKCo-3	Scientists sometimes collaborate and share expertise in order to generate new knowledge and refine existing knowledge in scientific disciplines. Most of the interactions occur by practicing scientists consulting existing knowledge/research or technology	"it's gonna put that information out there for someone else to maybe take it in a different direction. Everything kind of forks. You've got where your paper got you. Now that researcher may want to go this way with it but another one could take it in a whole different direction and I think that's the importance of, of collaboration and sharing. That it's the chance to, to make new discoveries when that research may have never been done had it not been shared." (T3, post-

		developed by their predecessors.	program NOS Interview)
	NOS_SKCo-2	Scientists primarily develop new scientific knowledge independently, but may build upon the existing ideas established by their predecessors. Scientists may interact with one another in order to generate ideas, but the role of individual expertise in building knowledge is not emphasized.	"You don’t dive into a huge, big problem. You take knowledge that’s already existing, you go through papers. Find something of interest within that paper and try to take that a little bit further. Um, then it's all about, by comparing the results and then seeing what next aspect of that you want to, to dig a little bit deeper with." (T3, post-program NOS Interview)"One set of eyes and one, or, one, yeah, one set of eyes and one brain’s only gonna give you one perspective. So more eyes, more ears, more input, kind of deal, allows this process of brainstorming. I may not come up with an idea that somebody else does, but I may like their idea that they come up with." (T4, post-program NOS Interview)
	NOS_SKCo-1	Scientists develop knowledge independently. The ways in which scientists interact with one another in order to build knowledge are not acknowledged.	"they were working independently of each other at some point in time, and, or other people were, and they came up with two different hypotheses. And they came up with two different experimentations. And, you know, just looking at the data that was present, both of them fit." (T4, pre-program NOS Interview)
Modeling and Inscribing: Types of Models	NOS_Mod-4	Scientists primarily strive to model the natural world in their work. The models employed in this work take many forms (e.g., structural models, computational models, experiments, mathematical models, etc.) and are generated using a variety of methods. These models reduce the phenomenon to a more interpretable form, while simultaneously amplifying it in terms of its applicability to other, related	"oversimplification, to the point of being incorrect. Um, and that would be a drawback. The advantage is we can now at least give them an idea that, and, and, the, the key is how you introduce it. I think the biggest problem is when we introduce the picture of the atom, I’m really careful to say, look, this is a, a human representation of something. It’s not totally accurate, but it’s a, one that we work with and it gives us pretty good answers, so that’s why we use it. And I think, unfortunately, some people, when they teach that model, make the kids memorize all the little nuances of the simplified model. Well, those aren’t correct. They’re just there as a, kind of a hook to get you interested and get you to understand more about how we do science and what’s going on in

	phenomena.	science." (T1, post-program NOS Interview)
NOS_Mod-3	Scientists strive to model the natural phenomenon they are investigating using physical/structural models, computational models, and/or mathematical models to make some aspect of the world more understandable. Experiments are not viewed as a type of model.	"most of the models there would be mathematical. We build a set of equations that define how things will, will happen and then we throw stuff at it and we see what the model generates and then we go into the lab and see what it generates in the lab, and if those two correlate we feel pretty good about the model. If they don't correlate then we need to go back and say, well what's going on? And, um, why don't they? I mean, in, you know, supposedly these two things should fit. But in many cases at young ages models are more physical. Because it gives people something concrete to, you know, I mean, um, it goes so far even as to building bridges out of K'nex to show them that a triangle's a better shape than a square to hold weight. That kind of thing because a lot of kids, even though they'll read in a book and see it, and they geometrically say, oh yeah, that makes sense, they still don't really buy into it. Then you have 'em build something and break it and they realize, wow, that really did work." (T1, pre-program NOS Interview)
NOS_Mod-2	Models in science only consist of physical/structural models (e.g., atomic models, anatomical models) meant to represent some aspect of the world on a more manageable scale.	"you've got the, the DNA models, you've got atom models, you've got polymers; uh, (inaudible) bridges, uh, you use those models, constructions, uh, uh, architectural work, stuff like that." (T5, pre-program NOS Interview)
NOS_Mod-1	Scientists use models in their work but no explanation is provided about how they are used, or there is no acknowledgement of the use of models in	(None available)

		science.	
Historical & Contemporary Context: Beliefs & Values	NOS_CB&V-4	Societal values, as well as scientists' personal values and beliefs about the world, all influence the types of questions pursued, methods employed, and approaches to analysis in research. Societal beliefs and values may influence the types of research supported by different funding sources, such as the federal government.	"what one person views as socially or ethically immoral, another person may not view as socially and ethically immoral...would I have an issue with people performing, uh, biological or medical experiments on rats. Personally, no, I wouldn’t, but does that mean somebody else would? Well, I mean, from what I can glean from the news, there’s definitely people in PETA that really don’t like animal experimentation whatsoever. I personally can sit here and think, you know, I’d much rather they test it on a rat before it gets tested on me, whereas somebody else may say, you know, I’d rather they didn’t do that. So, that person that is against animal research would say, you know, I would never do research on another living organism. That’s just not part, that’s part of their belief structure, that’s part of their moral structure. They’re not gonna do it, whereas I might go and get the same chance that they had to perform, I don’t know, bone reconstruction on a rat. And even though I might think it kind of gross, I could do that and not have a social or moral obligation or objection to it, and, and be okay with that" (T4, pre-program NOS Interview)"You can change presidents and all of a sudden the amount of money flowing into science and different areas changes dramatically. Um, and so you, you realize that that has a huge say in what’s gonna get done. Now it may not have the say in what corporations do. They can be immune to it if they’re big enough and they, and they fund their own research, but as far as governmental research, which, you know, National Institutes of Health, Department of Energy, uh, National Science Foundation, all that’s a lot of our research budget, and so, yeah, they can afford to, they can affect what will get done and what won’t get done, and in many cases the decisions aren’t made by people in science. So therefore people can put,

		well this type of research is more important than this, or we don’t wanna do that ‘cause it’s, that’s against something that I don’t wanna, you know, my belief or whatever." (T1, post-program NOS Interview)
NOS_CB&V-3	Societal values may influence the types of questions valued in scientific research and/or the methods used to pursue these questions. Scientists' personal values and beliefs may influence the types of questions that they investigate, but they remain objective when selecting their methods for investigating these questions or interpreting their results.	"either government or maybe department or, um, even maybe personal, you know, something that's happened to them personally or to a family member when they, they would sit there and say, you know, how could I do this differently, how could I make this better? And, you know, they would, you know kind of formulate a question from there." (T2, pre-program NOS Interview)
NOS_CB&V-2	Societal values may influence the types of questions that are valued in scientific research. Individual scientists, however, are objective and do not allow their personal beliefs or values to influence the research they pursue, although they may build upon their own background knowledge when developing their research questions and methods for investigating them.	"where society is kind of going, um, with things. Um, where you're department maybe (inaudible) so I think it, it has a lot to do with just kind of, um, I would guess just kind of the world type things or, or political I guess would, would be a big push in what research is being done." (T2, pre-program NOS Interview) "I think you're gonna work with things that you already have a lot of background knowledge, try to produce results with those. So you can then try those results with ones that are, are less familiar." (T3, post-program NOS Interview)

	NOS_CB&V-1	Societal and scientists' personal values and beliefs have no impact on the types of questions researchers pursue and the means by which they investigate them, as scientists and their work must remain objective. While scientists may require some form of background knowledge (e.g., familiarity with certain laboratory techniques) to conduct research, this knowledge does not influence their work so that they remain unbiased in all aspects of their work.	"Scientific research has become too global to limit itself to a few nation's desires, values, or culture." (T4, post-program NOS Questionnaire) "when I think about science I, you know, I take the religion out of it. Um, religion and philosophy, religion, faith, you know, and then you've got to know about what's faith you know, and that's a personal opinion. So science is cut and dry. It is what it is." (T5, pre-program NOS Interview)

Appendix H

Instruction Codes and Sample Responses

for Teacher Talk Related to Focal Constructs

Focal NOS Construct	Coding Scheme		
	Code Name	**Code Description**	**Sample Response(s)**
Intellectual Interdependence: Intra- and Interdisciplinary Exchange	InsTT_II-5	Teacher talks about the need to facilitate activity and discussion to help students understand the importance and implications of connections among different science disciplines, as well as ways that individuals may specialize in and share knowledge across and within disciplines. Teacher describes specific opportunities and/or plans for integrating science disciplines through intra- and interdisciplinary exchange with students in other science disciplines and/or with practicing scientists within his or her instruction.	"I think the DBS unit is definitely one they can do a lot of it on. I've been very pleased with how much anatomy and physiology they can come with up on their own. I introduced one young man to a software that's free on the web to read MRIs and CTs and I think they actually found the STN on one site. I'm gonna send that over to [a researcher] in the lab and say, is this actually it, did the kids actually nail this?" (T1, post-program Instructional Interview)
	InsTT_II-4	Teacher talks about the need to help students understand the importance and implications of connections between different science disciplines and the ways researchers collaborate with individuals across OR within disciplines. Teacher describes	"I refer a lot back to the RET program and...how the engineers there go about doing things and how it's different from what I...always had an idea of how it was done, but not to that degree...I thought if you were researching medical stuff that you had a medical background. Well, there's students there, or, or researchers there who are researching medical stuff and

	specific opportunities and/or plans for intra- and/or interdisciplinary exchange among students within his or her individual classes.	have no medical background whatsoever, that's not what they're there for. They're there because they know the computer aspect of it, or they can build things, or...they know...how the machines work. But as far as the...actual medical stuff behind it, they have no clue, other than what they've just learned to be able to have an idea of how it's gonna...affect everything else." (T2, post-program Instructional Interview)
InsTT_II-3	Teacher discusses the fact that students should understand that researchers work in cross-disciplinary teams. Teacher talks generally about connections between his or her course content and content addressed in other courses. Teacher describes importance of asking students to think about interdisciplinary topics/issues but does not describe plans for students to do so through intra- or interdisciplinary exchange.	"for anatomy, example...the kids, they don't understand the importance of...having taken all those classes...and having some understanding about it. When they take physical science as a freshman, or when they did, it never occurred to them that they would be...looking at a simple machine in the form of a skeleton and how it works with the...leverage system, how it works with the muscular system. They don't realize that...that's just a very small concept in one of the larger...disciplines that shows up, the same with...organic molecules...carbohydrates and things like that. Those are shared throughout...the different disciplines, so I think it's very easy to say that it, there's a lot of things that are spread across all the disciplines." (T2, post-program Instructional Interview)
InsTT_II-2	Teacher acknowledges that students should understand that researchers work collaboratively, but does not emphasize the intra- and interdisciplinary composition of research teams. Teacher does not emphasize nor	"science works as collaborations because a group of people can be more productive than the individual. And so that's what I want the kids to see is, and when we talk about it, um, we were, something was being discussed about Nobel Prizes, and I said, well, there are some things we'll never award a Nobel Prize for. I said, for

		discourage interdisciplinary thinking. Teacher acknowledges opportunities for interdisciplinary instruction but does not describe any plans to provide such experiences. Teacher discusses opportunities for students to share information to expand the breadth of topics addressed, or share data with one another for the purpose of experimental replication, but does not explain how this may be built upon to expand student understanding of an interdisciplinary concept.	example, like, we’ve given Nobel Prizes for some particle discoveries, but we don’t gi, we won’t give it for say, the top quark. At least, that, we’ve, it was pretty much said that when it happened because that was a collaboration of well over two hundred people, and they don’t give Nobel Prizes to that type of collaboration. And the experiment design was not a single person. It was a design of a group, and the analysis was a group." (T1, pre-program Instructional Interview) "we actually already did a lab where I kind of assigned different pieces and we put the data up there together. I had three groups working on, on one temperature range, when we were looking at respirometers, um, O_2 consumption, and then I had three other groups working on a different temperature range, and then we, we kind of merged the data on the board together and discussed it." (T3, post-program Instructional Interview)
	InsTT_II-1	Teacher does not acknowledge/address intellectual interdependence in any way. Teacher does not in any way discuss how thinking about interdisciplinary concepts may help students understand science.	"So if they’re learning physical type of things, some part of physical science, in eighth grade, well, when they come up here to ninth grade and take a more in-depth physical science then that would carry over. But my physical science is not gonna carry a student into biology, except for like significant digits and graphing and things like that." (T5, post-program Instructional Interview)

Variability of Methodology	InsTT_VM-4	Teacher stresses the need for students to understand the different approaches to research employed by scientists both within and across disciplines, noting that not all scientists rely on experiment-driven data. Teacher emphasizes that different methodologies enable researchers to pursue different research questions and that they do not all follow a set of rigidly-defined steps, therefore addressing the lack of a universal scientific method. Teacher expresses desire to provide opportunities for students to engage in activities that allow them to determine their own methods for answering a question and provides concrete examples of how he or she does or plans to do so.	"the open-ended investigations I think definitely help where they're not told what to do. They're just given a problem, you figure it out. Um, construction projects, like mousetrap vehicles, balsa-wood bridges, Rube Goldberg designs...the Achilles tendon module, things where they have to go through and there is a stated, a stated objective but how they get from that question, or how they answer that question then varies among each group or each individual as they go through...whether it's from a research standpoint of, well, how did other people build a mousetrap vehicle, or what are some typical truss designs for a balsa-wood bridge to...the actual construction methodology...those kind of things, where it's not set, it's not concrete, they're having to learn a little bit on their own I think greatly helps their ability to think like a scientist, to think like an engineer, to maybe think outside of the box a little bit, not just take information that is given to them and do something with that which would be rote memory" (T4, post-program Instructional Interview) "from what I've seen, scientists all do their work differently...I don't think every scientist does their work, their exploration, in the same format as the next person, and so to come up with one standard approach to...science...it's not feasible. I don't think it is, anyway. So, see, we have come up with a way...to approach science labs and...how to get these kids started off somewhere." (T6, post-program Instructional Interview)

	InsTT_VM-3	Teacher acknowledges that students should understand that researchers employ different techniques when attempting to answer their research questions, but emphasize that all still use the scientific method OR that they rely on experiments to generate data. Teacher expresses desire to provide students with the opportunity to engage in more authentic research activities, but does not communicate clear plans for doing so. Teacher may discuss need for engaging students in more structured lab activities in order to help develop their understanding of equipment or particular concepts, but drawbacks of this approach are acknowledged and importance is therefore placed more on open-ended investigation.	"we do that all the way up, and I do that, I use that to teach them how to use the equipment, the basic sensors we have and the basic mechanism of doing an experiment and analyzing data, because I don't think you can just throw 'em into it without some guidance. Once they've gotten that, I think there's real benefit in allowing them to determine how to test something out. So they have to be part of that. I don't think you can ever just start from scratch and construct the idea of the scientific method from a vacuum. I think that they need to be told there are reasons why we do certain things, and repeatability is one of those. That's the main one. So, you know, I have no trouble with that. I just...don't think you'd wanna do that all the way through a student's career. I think at some point, to teach them what really goes on in science...you have to be able to say...real scientists come up with real questions that have never been asked before and try to find those answers. Somewhere down the line the kids need to see that. Otherwise I don't know, how would science be any different than being, you know....a book-keeper and a teller at...a bank, not to put that occupation down, but you have a set of instructions you follow that's mandated by some organization, and if you just follow those, everything's fine. That's not what goes on within science and real research." (T1, post-program Instructional Interview)

	InsTT_VM-2	Teacher acknowledges that students should understand that researchers employ different techniques when attempting to answer their research questions, but emphasize that all use the scientific method AND rely on experiments to generate data. Teacher expresses value of or desire to provide opportunities for students to engage in more authentic research activities, but does not consider this a realistic expectation given various constraints on teaching and/or students' background knowledge. Teacher discusses instructional value of more structured and scripted investigations. Teacher may explain that students are permitted to pursue different approaches to certain class assignments, but this is not carried over into students' investigations.	"I usually give ‘em an area of topic to study so that they just don’t go off on the deep end. Um, they bring their topic back to me to be approved, just to make sure that they’re gonna be able to find information on that topic. A lot of 'em try to find the rarest thing in the world and it’s got a...paragraph article on what it actually is. So...I approve their topic and then it’s...up to them after that. Um, they know that they have to turn some kind of research paper in to me, and they know that they have to give me some kind of presentation and whatever they decide to do...however they decide to do that is up to them." (T2, post-program Instructional Interview) "they should learn definitely the scientific method and how that goes about; and other than that, I think the rest of it is gonna be student-dependent. Higher end students may learn more specific topics in let’s say...physics or calculus or...applicational sciences...some of the...lower-functioning students might not learn so much about the quantitative sciences in high school and they learn more about the qualitative kind of deal, but I think it still goes back to what they should all learn. They should learn how to think for themselves, how to do critical thinking, how to...graph and apply mathematics to science, how to come up with their own experiment and carry through on it." (T4, post-program Instructional Interview)
	InsTT_VM-1	Different approaches to research employed by scientists are not emphasized. Teacher emphasizes that scientists follow the	"it all just kind of plays back to that same idea...and if you even take it to another level, that is, you know, not every student you have is gonna go into a science field, moving on

		scientific method and rely on experiments to generate data. Teacher does not describe any desire or need to engage students in more authentic research activities and emphasizes the value of structured, scripted investigations.	with their life...the overall binding skill that would carry through to whatever they look at would still be that problem-solving process, that logical step-by-step process of, I've got a problem. How do I solve that problem? Well, I need to come up with some kind of an idea, some kind of solution, a.k.a. hypothesis. And then, you know, work through your experimentation and gather your data...You know...even if you look at like just life in general versus, you know, like a science class or a physics class, a chemistry class, it all just kind of, that's the common denominator across the board." (T4, pre-program Instructional Interview)
Scientific Knowledge: Generative	InsTT_SKGen-4	Teacher emphasizes that students should understand that scientists primarily work on projects that strive to generate new knowledge and advance scientific understanding of natural phenomena rather than verify it. Teacher acknowledges that most school science focuses on verification or the pursuit of expected results and describes plans for engaging students in open-ended investigations that may result in the generation of different and unexpected outcomes. Teacher emphasizes the importance of examining discrepant or unexpected results for moving scientific knowledge forward.	"as long as you keep those groups moving so that they are constantly looking back to say what did we ask, what are we trying to do, to find out...is our data answering that question, or have we somehow strayed off the path and we're not answering the question any more...can't always say to a kid, well, now that's garbage, because a lot of the outliers tend to be, in real research can be very important. In a lot of the stuff we do in high school it, it can be if they're not going down the path they've probably made mistakes and what they're getting is pretty much bad data and garbage...but it's a...good point at that time to say to the kid, now you do realize that a lot of...discoveries were found by going along a path and you get these outliers and instead of doing what you always do, which is show that those are outliers and throw them away, someone took those outliers and said, wow, this is really important. And out of that came the discovery. This never panned out. So I should

		never just throw out the outliers because they're two standard deviations off. Make sure that they're...off because you can find the mistake...and I explained to the kids, that in our labs, pretty much if you're that far off, given that we're not dealing with quantum mechanics...you probably made a mistake...I think that gives kids an inkling into, oh, so they don't always know how to get from point A to point B. They have to actually work at it." (T1, post-program Instructional Interview)
InsTT_SKGen-3	Teacher emphasizes that students should understand that scientists work to both generate new and verify existing knowledge about natural phenomena OR acknowledges that school science focuses primarily on verification and the pursuit of expected outcomes. Teacher expresses desire to engage students in open-ended investigations that provide the opportunity for consideration of differences in results and their importance in moving scientific knowledge forward, but does not describe any specific plans for doing so.	"students need to come in and say, I'm gonna do this lab but...if it messes up and I don't get a result that...is expected, I need to be able to go back to my work, find the problem, and see if it can be corrected. Because that problem that may have happened and gave me the new result, not the failed result but the new result, could be a new discovery...But they can't be like, oh man, I got the wrong answer. This isn't gonna work. No, you got a new answer. Why did you get the new answer? Is this something new that [T5] didn't even know about? Some new discovery? Could be anything. So we need to be able to go back, don't think failure, think new idea. Where's the problem? If it is a problem, can we correct it and get the result we expected? So...failure in the lab is...great." (T5, pre-program Instructional Interview) "that would be...misrepresentative of science because when you test a hypothesis and form a theory you don't know what the outcome is gonna be...that's the whole point of research. You don't know yet what the

		outcome is gonna be so I can see where that would be misrepresentative of, of the scientific community because they don't perform a lab or study, research something for years, knowing that this is, 'cause they may not have anything there, there may be no positive results from their labs. And so when we do our labs, I know that they're gonna find a certain amount of dissolved oxygen in, you know, this water sample, because of, you know, whatever we had in there before. So, I don't know, I can see where that would be misrepresentative." (T6, pre-program Instructional Interview)
InsTT_SKGen-2	Teacher emphasizes that students should understand that scientists primarily work to confirm or verify existing knowledge and that new knowledge or understanding rarely emerges. Teacher expresses desire to engage students in an investigation that would provide them with an opportunity to discuss why they may have obtained different results, but does not emphasize the way in which this may still lead to the development of new knowledge.	"We pretty much follow the procedure that the...the materials come with. Um, when we go back and analyze results, that's when we have...discussion and that's where most of our...inquiry takes place 'cause then they go and try and trouble-shoot and figure out, alright, we know what our expected results were because we were following this procedure. This group ended up with this number that's way out here in left field. Why did that happen? And then they'll go in and trouble-shoot each other and try to figure out why they would have had such a...big error. And that's kind of where we get into some really good discussion in class." (T3, post-program Instructional Interview)

	InsTT_SKGen-1	Teacher does not stress the role of knowledge development in science. Teacher describes importance of students participating in investigations that are expected to yield particular results in order to reinforce understanding of a concept.	"some experiments are what I call the quick and dirty ones...you demonstrate it, it has one specific point to show. They can actually collect data and get enough numbers in a fifty-minute class period to, to talk about the fact that, hey, this worked. But it's usually a pretty simple thing...Hooke's Law, for example, where you hang massed weights on a spring, and then you measure the length of the spring, when you plot the weight, the force on the spring versus its length, it's perfectly linear. That's something they can do in twenty minutes. It's so easy, they get a great answer, everybody's happy, they all...know something, they believe the book now." (T1, pre-program Instructional Interview)
Scientific Knowledge: Co-constructed	InsTT_SKCo-4	Teacher emphasizes that students should understand that scientific knowledge is built through the co-construction of knowledge among researchers, which requires that they draw upon the expertise of others in order to generate thorough descriptions of the natural world. Teacher discusses plans for students to co-construct a classroom-level understanding of concepts through development and exchange of expertise among students.	"the wind tunnel did really well...next year that'll come back out to improve it...I want them to look at what...this group did and I think there are two things that they can improve on. They can improve on the air flow, on how it passes through the wind tunnel by making a polar pusher or a closed-in tunnel which is another option. I think that they...can build the model better. And that they can understand more of the aerodynamics and the math behind it...I look at this year as a building year and then next year's students can come in and improve on it, and I think you could carry some ideas year to year" (T1, post-program Instructional Interview)

	InsTT_SKCo-3	Teacher emphasizes that students should understand that scientific knowledge is built through the co-construction of knowledge among researchers. Teacher discusses potential benefits of building classroom-level understanding of concepts by asking students to work together to do so, but does not describe specific plans for doing so.	"If you have two or three and you get stuck, you have more chances for someone in the group to come up with an idea to keep the group going or figure out a problem and help the others out. They all have their own strengths, and so what you're hoping is some sort of collaborative movement of the group through the experiment. And you're hoping that they talk to each other, because if they're talking about the experiment, then they're reinforcing certain ideas...most people do better with…someone next to 'em because they feel like, if I get stuck you can help me. I'll help you and we'll...get through this together." (T1, pre-program Instructional Interview) "I think, by working in the groups...of four you are gonna have more discussion, hopefully, and disagreement. But by trying to overcome that disagreement you can have the discussion takes place where maybe they'll end up with a deeper understanding of...why the right answer was reached. And that's what I'm hoping for when we work in groups of four rather than a traditional lab partner where you just work with one other person. I know the way I do my labs are a little bit different than, uh, some of the other teachers in my department, but I think working in...larger groups is more related to...how it is in the real world." (T3, pre-program Instructional Interview)

	InsTT_SKCo-2	Teacher makes reference to the fact that students should understand that researchers may draw upon the knowledge of others in some way, but fails to make clear the role of this collaboration for the generation of new scientific understanding. Teacher discusses general benefits of student-centered instruction (e.g., students working together to help generate ideas or discuss a concept), but does not emphasize how this might help them develop conceptual understanding of a topic.	"sometimes...for the labs that...require it we'll have like a spokesperson, so if we do an activity where they're having to do some research, someone will be the...person that...navigates through the different websites when we look the information up on the computer. Someone will be the scribe, someone will have...to be the...person that speaks to the class about what they found. And as we pull the information together from the different groups, everyone's kind of taking some sort of role in that activity." (T3, pre-program Instructional Interview) "I always work in groups. Number one, just because we don't have enough materials to not, or enough space to be singles. But the other reason is because of teamwork. That's what science is. You don't go in there and just, you're not the only person doing a lab or whatever. No, there's a team of you, of people doing it. So you might as well get 'em used to it." (T5, post-program Instructional Interview)
	InsTT_SKCo-1	Teacher fails to emphasize any ways in which scientific knowledge is built through the co-construction of knowledge among researchers. Teacher focuses on imparting knowledge to students through teacher-driven instruction.	"you go to graduate school, they teach you that it's better for kids to work in pairs and to work in groups and to share and to...present, but I've really found that through lectures and demos that's probably the most effective way to communicate whatever it is" (T6, post-program Instructional Interview)

Modeling and Inscribing: Types of Models	InsTT_Mod-4	Teacher explains that students should understand the central role of modeling in science as a means to understand and natural world by reducing the phenomenon to a more interpretable form, while simultaneously amplifying it in terms of its applicability to other, related phenomena. Teacher stresses importance of providing students with opportunities to develop and use a variety of models to help them understand its central role in scientific research, as well as course content, and describes specific plans to do so.	"I doubt very many scientists are out there building balsa wood bridges. Um, but at the same time, I think the goals are the same. You want to take something that's very complex and you want to simplify it. You want to simplify it with this model. And this model should demonstrate the macroscopic, main qualities that you're trying to test and kind of leave out some of the other stuff that you're not worried about. And I think for this most part, the things that they're gonna look at with these models that they create or a computer-generated...java applets on the screen as it's gonna...do that. It's going to take the macroscopic and it's going to enhance that. The bridges, it's gonna look at force and it's gonna look at torque and it's gonna look at pressure. Or the mousetrap vehicle's gonna look at torque and speed and acceleration. And the catapult's gonna look at torque and it's gonna look at tension and it's gonna look at, um, elasticity." (T4, pre-program Instructional Interview)
	InsTT_Mod-3	Teacher explains that students should understand some of the types of models employed in scientific research and the ways in which they are used to advance understanding of the natural world by representing a phenomena in an interpretable form. Teacher talks about how creating or interacting with a variety of different types of models may help students better understand certain	"They're telling a story of what happens on a much smaller scale than real life...you've gotta make 'em bigger in scale so it's easy to see what's happening and I thought the students did a pretty good job doing that. Um, now there's other types of models that scientists use, like statistical models where they can...plug in data and be able to make projections based on the data that they've obtained. I don't think we do a whole lot of that in, actually I know we don't, there's a...population one that we do that kind of touches on that when we look at some statistical analysis, but we don't use a whole lot of

		concepts.	mathematical...models in here." (T3, post-program Instructional Interview)
	InsTT_Mod-2	Teacher explains that students should understand how a certain type of model is used in scientific research. Teacher talks about the ways in which creating or interacting with a particular type of model, such as a structural model, can help students visualize a concept.	"Just a, a visual image of, of what it was that we're talking about. There's a lot you can remember something if you see it than if you just were told about it." (T6, post-program Instructional Interview)
	InsTT_Mod-1	Teacher does not explain a need for students to understand the use of modeling in scientific disciplines, nor any ways in which creating or interacting with models might be useful for classroom instruction.	(None available)
Historical & Contemporary Context: Beliefs & Values	InsTT_CB&V-4	Teacher discusses the importance of students recognizing ways in which societal and personal beliefs and values influence the types of research pursued in science and the extent to which these values may impact the types of questions pursued and/or the funding available for particular research questions. Teacher describes specific plans for asking students to consider how the beliefs and values of society and scientists may influence the types of questions pursued and methodologies used in research.	"in most research there is a, a point they have to get to, obviously, if they've gotten a grant that they have to do something, that they definitely need to get there and part of that's driven by funding, that they have to come up with an answer. Um, I can make that artificial in class by saying...this is your grade. You know, and...I've teased the kids before, saying it's gonna be A or F. You either got funding and now you get to survive, or F you failed and you're out on the streets" (T1, pre-program Instructional Interview)

	InsTT_CB&V-3	Teacher discusses the importance of students recognizing the ways in which societal and personal beliefs and values influence the types of research pursued in science. Teacher expresses desire for students to consider how the beliefs and values of society and scientists may influence the types of questions pursued and methodologies used in research, but does not describe any specific plans for doing so.	"The main thing that I try to teach my students is to think for themselves...some of the data is skewed...you know, how people can take something and make it for their point, I guess is what I guess I’m trying to say. Instead of, you know, what it, what it’s really saying at that point." (T2, post-program Instructional Interview)
	InsTT_CB&V-2	Teacher discusses the importance of students viewing science as objective, but also talks about asking them to consider some influences on the types of research that is valued. Teacher expresses desire for students to consider how the beliefs and values of either society or scientists may influence the type of questions pursued in research, but does not describe any specific plans for doing so.	"I don’t think they understand or know much about these events that were pretty significant. Um, Chernobyl would probably be the most of the two but, uh, as far as what I wanted them to take away, I just wanted them to understand a little bit more about nuclear energy, um, the advantages, the disadvantages, how can we use it in the future or maybe we shouldn’t use it in the future, and for them to make a thorough opinion about that" (T6, pre-program Instructional Interview)
	InsTT_CB&V-1	Teacher discusses the importance of students understanding science as remaining objective and immune to any personal or societal influence. Teacher emphasizes need for students to work objectively and not allow their own beliefs or values to influence their work.	"when you start getting into controversial things, evolution, uh, stem cell research, things like that. You know, people start, people, kids want to bring in their religion...when you start talking evolution and they say, you know, the kid says well, that's how God made it. Then we have to educate kids on no, this is where you leave God out of it" (T5, post-program Instructional Interview)

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