K-12 TEACHER PROFESSIONAL GROWTH FOR NATURE OF SCIENCE AND SCIENTIFIC INQUIRY: PROMOTING REFLECTION THROUGH EXEMPLARS

by

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This work is dedicated to my daughter Shannon. Do what you love.

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ABSTRACT

Developing K-12 science teachers' understandings of nature of science (NOS) and scientific inquiry (SI) continues to be a major goal of science education reform. There is consensus among science teacher educators that developing students' NOS and SI understandings is vital to the development of a scientifically literate citizenry. However, two decades of research have shown that science teachers continue to hold views of NOS and SI incongruent with reform recommendations.

The research presented here consists of two studies which examined the effectiveness of explicit and reflective (ER) interventions designed to promote teacher professional growth for NOS and SI. Following a brief introduction to the problem (Chapter 1), the dissertation begins with a comprehensive review of the results of ER interventions to promote K-12 teacher professional growth (Chapter 2). Next, a mixed-methods, quasi-experimental study design was used to compare the influence of ER NOS interventions on preservice elementary teachers' conceptions of NOS and SI and their intentions to integrate NOS in their future classroom practice (Chapter 3). One course section received an ER NOS intervention using NOS standards documents (NOSSE ER Strategy) while the other group received an ER NOS intervention that incorporated ostensive exemplars (NOS Example Strategy). Participant reflection was assessed as they engaged in the interventions, and NOS and SI conceptions and intentions were compared pre and post intervention. Both interventions promoted teacher reflection on NOS and SI, but participants in the strategy group that incorporated ostensive exemplars exhibited more (d = 1.07) reflection, though these were not statistically significantly different.

Both interventions promoted positive changes in preservice teachers' conceptions for NOS and SI. Participants in the NOS Example Strategy group perceived themselves as more ready to integrate NOS in their future classroom practice than participants in the NOSSE ER Strategy group.

Study two (Chapter 4) examined how and to what extent using ostensive exemplars promoted teacher professional growth for NOS and SI for two high school biology teachers. Results indicated that the use of students' exemplar responses promoted teacher reflection, resulting in positive changes for NOS and SI conceptions and intentions to integrate NOS in classroom instruction. The dissertation concludes with a short summary of the relevant results and their impact for future ER NOS interventions to target teacher professional growth (Chapter 5).

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CHAPTER ONE: INTRODUCTION

Problem Statement

Developing K-12 science teachers' epistemological understandings of nature of science (NOS) and scientific inquiry (SI) has been and continues to be a major goal of K-12 science education reform (e.g., American Association for the Advancement of Science [AAAS] 1990, 1993; National Research Council [NRC] 1996, 2000, 2011; National Science Teachers Association [NSTA] 1982; NGSS Lead States, 2013; among others worldwide). There is consensus among science educators that NOS is vital to the development of a scientifically literate citizenry (Driver, Leach, Millar, & Scott, 1996; Bybee, 1997; McCain, 2016) and this view continues to be emphasized in the most recent iteration of national K-12 science standards (Lead States, 2013). For example, Appendix H (p.2) in NGSS states, "[o]ne fundamental goal for K-12 science education is a scientifically literate person who can understand the nature of scientific knowledge." Yet, in general, our nation's science teachers continue to hold conceptions of NOS and SI that are incongruent with science education reform recommendations (Abd-El-Khalick & Lederman, 2000; Lederman & Lederman, 2014), making it very difficult to meet the educational goals set forth in reform documents.

What are NOS and SI for Science Education?

Disagreement about what constitutes *the* NOS abounds in the literature (Abd-El-Khalick, 2012; McCain, 2016; Irzik & Nola, 2011) despite agreement among most science education researchers in K-12 settings of a consensus NOS view in which there are general characteristics of scientific knowledge that are agreed upon and considered appropriate for K-12 science instruction (Smith, Lederman, Bell, McComas, & Clough, 1997; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Abd-El-Khalick, 2012). This dissertation is guided by this consensus view and defines NOS as the epistemology of science (science as a way of knowing) which includes the “values and assumptions inherent to the development of scientific knowledge” (Lederman, 1992, p.331). The process used to generate this scientific knowledge is referred to as scientific inquiry [SI] (Lederman, 2007). Science education researchers have developed aspect lists to assist in defining, measuring, and reporting teachers’ and students’ views of SI and NOS. The NOS and SI aspects that guided this dissertation (Bartos & Lederman, 2014) are as follows:

Scientific Inquiry: Generating Scientific Knowledge

1) Scientific investigations all begin with a question.
2) There is no single scientific method.
3) The procedures of a scientific investigation are guided by the question asked.
4) Scientists following the same procedures will not necessarily arrive at the same results.
5) Procedures influence results.
6) Conclusions must be consistent with data.
7) Data are not the same as evidence.
8) Scientific explanations are developed using both evidence and what is already known.

Nature of Science: Characteristics of Scientific Knowledge

1) Scientific knowledge is empirically based.
2) Observations differ from inferences.
3) There is a distinction between scientific theories and scientific laws.
4) Scientific knowledge is a product of human imagination and creativity.
5) Scientific knowledge is theory-laden.
6) Scientific knowledge is affected by society and culture.
7) Scientific knowledge is tentative yet durable.

Professional Development of Teachers for Teaching NOS and SI

Due to the complex and multifaceted nature of NOS and SI, there are inherent challenges in developing teachers' conceptions of these constructs (Lederman, et al., 2002). Researchers recognize that changing teachers' conceptions of NOS has been most successful when explicit and reflective (ER) approaches are used (Abd-El-Khalick & Lederman, 2000). ER strategies, not to be confused with direct, didactic instruction (Khishfe & Abd-El-Khalick, 2002), use teacher questioning, small-group, and class discussion to make targeted aspects of NOS and SI *explicit* and provide time for learners to *reflect* on their understandings (Lederman & Lederman, 2004). However, even when teachers engage in professional development for NOS that incorporates ER approaches, some teachers do not develop adequate views (Abd-El-Khalick & Akerson, 2004; Akerson, Buzzelli, & Donnelly, 2008). In addition, if teachers *do* develop adequate NOS understandings, oftentimes they choose not to integrate NOS into their classroom instruction (Akerson & Abd-El-Khalick, 2003; Lederman, 1999; Bartos & Lederman, 2014). Identifying more effective ways of changing teachers' conceptions and facilitating the transfer of new conceptions into classroom practices are two problems facing NOS teacher educators that require further research.

This dissertation is a non-tradiational format and is divided into three analytic chapters written as stand-alone manuscripts followed by a final concluding chapter that briefly synthesizes the results and findings of all three. I adopt the view that making NOS and SI aspects explicit for teachers and providing them with opportunities for *reflection* on these aspects is vital to meeting the goal of changing teachers' inadequate conceptions of NOS and SI. Numerous studies provide empirical support of this view for NOS and SI teacher professional growth (Akerson, Cullen, & Hanson, 2009; Bloom, Binns, & Koehler, 2015; Donnelly & Argyle, 2011; Akerson, Hanson, & Cullen, 2007; Akerson, Morrison, & McDuffie, 2006; Lederman, Lederman, Kim, & Ko, 2012). Therefore, each paper in this dissertation focuses on teacher professional growth for NOS and SI, specifically regarding how to change teachers' inadequate conceptions by making aspects of NOS and SI explicit and providing a context for teacher reflection. All three papers use the Interconnected Model of Teacher Professional Growth [IMTPG] (Clarke & Hollingsworth, 2002) as an analytical framework (Figure 1) to organize factors identified as important to promote teacher change (e.g., teacher knowledge and beliefs, intentions, desired student outcomes, and teaching practices, among others) and identify mechanisms of change (e.g., reflection). The remainder of this introductory chapter summarizes the structure of the dissertation.

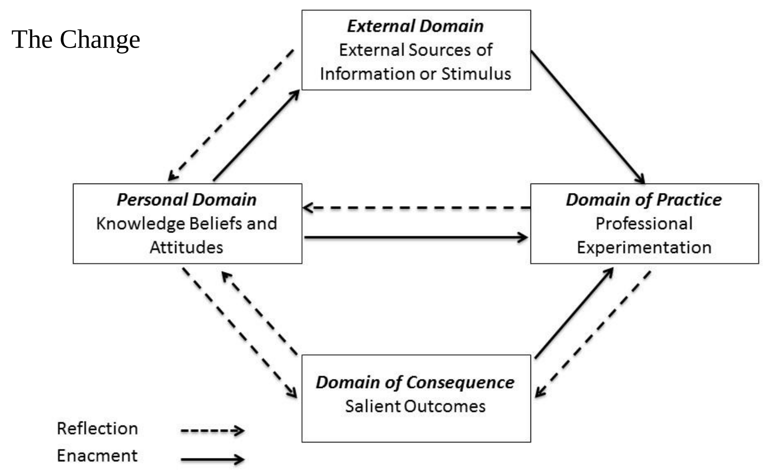

Figure 1.1. The Interconnected Model of Teacher Professional Growth. Adapted from "Elaborating a Model of Teacher Professional Growth," by D. Clarke and H. Hollingsworth, 2002, *Teaching and Teacher Education*, 18, p. 951.

Key IMTPG Terms

<u>The Change Environment</u> – the system in which professional growth occurs.

<u>Enactment</u> – the translation of a belief, knowledge, or experience into an observable action.

<u>Reflection</u>-per Dewey (1910, p. 6) "active, persistent and careful consideration" of existing beliefs (about NOS and SI) with reference to new information.

<u>Change sequence</u> – when change in one domain leads to change in another and is connected by reflective and enactive links that have been identified using empirical data. Both the change and causal mechanisms encompass a change sequence.

Growth network – a change sequence that is lasting, defined as "change that is more than momentary" (p. 958), signifying professional growth

Structure of Dissertation

Following this introduction, Chapter 2 is an analytic literature synthesis that examines the role of professional development on teachers' understandings and practices for NOS and SI in the context of the IMTPG framework. I examined a total of n = 39 studies that used explicit and reflective interventions as a means to improve K-12 teachers' conceptions of NOS or SI. Each study was critiqued using the IMPTG framework as an analytic lens through which to synthesize results across studies, with ER interventions considered part of the external domain.

The literature synthesis details how the majority of the research on interventions intending to change teachers' NOS and SI conceptions has been descriptive in nature (e.g., case studies) and has lacked control group comparisons. In addition, scholars have noted that changing teaching practices for NOS and SI is particularly difficult, regardless of the intervention approach. Based on the results of this literature review, I propose two areas for future research. First, more systematic research is needed to examine how and to what extent various ER interventions promote teacher reflection on NOS and SI. Second, a renewed focus on developing pedagogical tools is necessary to support teachers to effectively integrate NOS and SI into science instruction. These conclusions informed the development and analysis of the ER NOS strategies described in the two empirical studies that comprise Chapters 3 and 4 in this dissertation.

The two empirical studies examined the use of an ER strategy, referred to as the Nature of Science for Science Educators (NOSSE) Exemplar Strategy, conducted first with preservice elementary teachers (Chapter 3) and then with inservice, high school biology teachers (Chapter 4). The strategy was developed for this dissertation and was designed using the principle of ostention, where learners construct knowledge by differentiating key characteristics of concepts through the comparison of exemplars (Kuhn, 1974). Developing mental representations of concepts through rule-based classification schemes, prototypes, or exemplars is not new (Bruner, Goodnow, & Austin, 1956; Rosch, 1975) and ostention has been used to improve preservice teachers' conceptions of NOS in previous studies (Smith & Scharmann, 2008). However, the NOSSE Exemplar Strategy developed for this dissertation was unique in that it used exemplar responses from validated, open-ended NOS and SI questionnaires, transforming these research instruments into reflective pedagogical tools to make NOS and SI aspects explicit for teachers and to promote reflection. The testing of the NOSSE Exemplar Strategy was exploratory in nature and incorporated features of design experiments, such as a focus on theory development and use of iterative changes to the strategy while the experiment was in progress (Cobb, Confrey, diSessa, Leher, & Schauble, 2003).

In the first study, the NOSSE ER Strategy and the NOS Example Strategy were tested using a quasi-experimental, mixed-methods design in the context of a biology course for preservice elementary teachers (n = 34). In the second study, the NOSSE Exemplar Strategy was tested using a case study design in one-on-one sessions between each teacher and myself. In both studies, participants reflected on NOS and SI aspects using exemplar responses and standards documents. Collectively, both studies explored the overall patterns of teacher reflection that resulted in teacher professional growth for NOS and SI understandings, while examining the utility of tools that made NOS and SI aspects explicit for teachers. The implications for these collective analyses will be briefly discussed in the final chapter of the dissertation.

CHAPTER TWO: A SYSTEMATIC REVIEW OF EXPLICIT-REFLECTIVE INTERVENTIONS USED TO PROMOTE TEACHER PROFFESIONAL GROWTH FOR NOS AND SI

Introduction

For over two decades, science education researchers (e.g., Driver, Leach, Millar, & Scott, 1996; McComas, Clough, Almazroa, 1998; among others) have argued that developing adequate conceptions of nature of science (NOS) and scientific inquiry (SI) in K-12 settings is vital to increase student interest in science, enhance the learning and understanding of science content, and improve the ability of citizens to make informed decisions. Oftentimes, SI is conflated with NOS despite an important delineation existing between the two constructs (Abd-El-Khalick, 2012; Lederman, 2007). NOS is defined as the epistemology of science, science as a way of knowing, or the "values and assumptions inherent to the development of scientific knowledge" (Lederman, 1992, p.331). Though NOS and SI are intimately related (Lederman, 2006), they are distinct as SI is the *process* used to generate this scientific knowledge (Lederman, 2007).

The distinction between NOS and SI becomes more apparent when aspect lists generated by decades of education research are examined. While there is no single ubiquitous list, there are specific aspects of NOS and SI that often guide research on teaching and learning in K-12 settings (Table 2.1). Aspect lists of NOS and SI provide detail at a level of generality appropriate to be addressed in K-12 settings (Kampourakis, 2016; Lederman & Lederman, 2014) and can assist science educators in defining, measuring, and reporting teachers' and students' views of SI and NOS (Lederman, Abd-

El-Khalick, Bell, & Schwartz, 2002; Lederman et al., 2014; Schwartz, Lederman, & Lederman, 2008). While the focus of this literature review is on both constructs of NOS and SI, the literature is replete with instances where NOS is reported but SI is omitted due to the conflation of the constructs noted previously. Therefore, the use of the term NOS in the remainder of this manuscript is intended to represent both NOS and SI.

A Brief History of Teacher Professional Growth for NOS and SI

As early as the 1960s, a focus on NOS as a K-12 instructional outcome was evident as curricular materials were developed to improve science instruction and learners' conceptions of this construct. At this time, research began in earnest to determine the effectiveness of these science curricula, such as the History of Science Cases for High Schools (Klopfer & Cooley, 1963), the *Physical Science Study Curriculum* (Crumb, 1965), the Biological Sciences Curriculum Study (1960), and *Science: A Way of Knowing* (Aikenhead, 1979). The assumption at the time was that teacher implementation of a well-developed curricula was sufficient to produce the desired NOS student learning outcomes, regardless of the science teachers' NOS conceptions (Lederman, 1992). However, mixed results on the effectiveness of curricula, especially when student variables were controlled for, made it clear that science teachers play a pivotal role in the development of students' NOS conceptions (Abd-El-Khalick & Lederman, 2000; Lederman, 1992).

Table 2.1

Common Nature of Science (NOS) and Scientific Inquiry (SI) Aspects

Scientific Knowledge	Process of Generating Scientific Knowledge
NOS	SI
• Empirically based	• Investigations begin with and are guided by scientific questions
• Tentative, yet durable	• No single set or sequence of steps in a scientific investigation (no one scientific method)
• Subjective and theory-laden	• Data are not the same as evidence
• Product of human imagination and creativity	• Scientific explanations are developed using evidence and what is already known
• Theories & laws are distinct types of knowledge	• Conclusions must be consistent with data
• Society and culture affect scientific knowledge	• Scientists work in a community of practice
	• Scientists following the same procedures will not necessarily arrive at the same results

Note. This aspect list is not the only list of NOS and SI aspects but is generally representative of the consensus view of NOS and SI.

The second generation of NOS research revealed that teachers must possess adequate conceptions of both NOS and SI to begin to be able to transfer this knowledge into their classroom practices (Abd-El-Khalick & Lederman, 2000; Shulman, 1986; 1987). Yet data has consistently shown that teachers do not hold adequate understandings of these constructs (Abd-El-Khalick & BouJaoude, 1997; King, 1991; Lederman & Lederman, 2014). Therefore, developing K-12 science teachers' conceptions of NOS and SI has been and continues to be a major goal of science education reform (Lead States, 2013; NRC, 2012; NSTA, 2000). Two general approaches have been used by science teacher educators to improve teachers' NOS and SI conceptions. The first, referred to as the implicit approach, assumes that teachers will develop adequate conceptions of NOS and SI by engaging in the processes of science. However, this view is not congruent with empirical evidence from science education research (Abd-El-Khalick & Lederman, 2000) as "NOS understandings should be intentionally planned for, taught, and assessed rather than expected to come about as a by-product of teaching science content or process skills, or engaging students in science activities" (Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001, p. 3).

The second approach, the explicit approach, intentionally draws teacher attention to aspects of NOS and SI (Table 2.1). The difference between the two approaches in teacher professional development is how teacher-learners are presented with information to better understand key aspects of NOS as they engage in learning activities (Abd-El-Khalick & Lederman, 2000). Despite the intuitive appeal of using implicit approaches, there is ample evidence that explicit approaches combined with opportunities for teachers to reflect are more effective at changing teachers' NOS conceptions (Akerson, Abd-El-Khalick, & Lederman, 1998; Lederman et al., 2014; Matkins, Bell, Irving, & McNall, 2002).

Numerous studies have been published that attempt to evaluate the range of effectiveness of various explicit-reflective (ER) approaches used to improve pre-service and in-service teachers' understandings and pedagogical approaches for NOS and SI (Lederman & Lederman, 2014). This research often takes place in methods courses, science content courses for teachers, research experiences for teachers, and formal NOS courses, and can include a diverse array of strategies and approaches (McComas, Clough,

& Almazroa, 1998). However, in conflict with the goal of evaluating effectiveness, this diversity in contexts and interventions makes it difficult to synthesize conclusions across studies.

Goal of the Current Synthesis

Despite this, the overarching goal of this review is to describe various ER NOS interventions and identify areas of teacher professional growth that have not yet been sufficiently examined since research recommendations were made by Abd-El-Khalick and Lederman (2000) almost two decades ago. In their comprehensive review of teacher professional growth for NOS, the authors concluded there was a great need to conduct research to "identify and isolate the factors that constrain or facilitate the translation of teachers' conceptions of NOS into classroom practice" and better understand how these factors "impede or facilitate the translation of teachers' views of NOS into their instructional practices" (p. 696). Using the Interconnected Model of Teacher Professional Growth (IMTPG) as an analytical framework (Clarke & Hollingsworth, 2002), this current review is intended determine whether the past two decades of NOS research has identified, isolated, and tested the factors thought to promote or hinder teacher professional growth for NOS.

The following sections will first explain the literature search and the inclusion criteria. Second, the IMTPG framework used to analyze explicit-reflective NOS studies will be elucidated. I will then describe and critique key features of interventions used to develop teachers' understandings of NOS and SI and provide suggestions for future research regarding NOS and SI professional development for teachers.

Literature Search Process

In an attempt to conduct a thorough search of the literature, published journal articles, dissertations, and conferences papers were eligible for inclusion in this review. Professional development programs or university courses with the *a priori* objective of developing teachers' understandings of NOS, SI, or a combination of both, using an explicit and reflective approach were selected for inclusion. In addition, the conceptualization of NOS and SI used in the teacher professional development setting was required to be congruent with major reform documents in order to be included (NRC 2000, 2012; AAAS, 1990, 1993; NGSS 2013; NSTA 2000). Also important to note was the distinction made between SI as a learning objective and inquiry as a pedagogical approach to science instruction. For example, a PD program focused on developing preservice teachers' ability to include inquiry pedagogy would not be included in this review unless explicit attention on development of teachers' understandings of SI was also included. Finally, only studies published after the previously mentioned seminal literature review by Abd-El-Khalick & Lederman (2000) on improving science teachers' NOS conceptions were included.

A search of the ERIC database using the search terms "explicit reflective" and "nature of science" and "scientific inquiry" and "teachers" from the year 2000 to the present was conducted and abstracts of these studies were examined to determine if they met the inclusion criteria described above and in more detail below. Reference lists of these studies were then reviewed for possible inclusion of additional studies. A total of n = 39 studies met all the inclusion criteria and were coded for variables deemed important for teacher professional growth for NOS and SI. I acknowledge this review is not truly exhaustive, however, every effort was made to ensure a sufficient number of studies were included to represent the extent of ER NOS interventions that have been used with K-12 science teachers. Details of the specific inclusion requirements are outlined below.

Inclusion Criteria

1) The study must have tested an explicit and reflective intervention aimed at changing preservice or inservice K-12 teachers' conceptions of NOS or SI; NOS and SI are viewed as cognitive outcomes.
2) The constructs of NOS and SI targeted by the explicit-reflective intervention must parallel the conceptions as stated in science reform documents (NSTA, NRC, NGSS, AAAS, or a combination of these).
3) There must be some measure used to determine teachers' cognitive understandings of NOS or SI; a study that ONLY examines students' understandings will not be included because the focus is on reviewing the literature on approaches used to change teachers' conceptions of NOS and SI.
4) Studies published from 2000 through February 2017 were included. This time period was purposely selected based on a seminal literature review of trends in research on teachers' conceptions of NOS (Abd-El-Khalick & Lederman, 2000) as well as having NOS featured in K-12 science reform documents (AAAS, 1990; Lead States, 2013; NRC 1996; 2012; and NSTA, 2000) for approximately a

decade prior to 2000. These standards documents provided an impetus for conducting research on developing teachers' conceptions of NOS.

5) Primary studies from peer reviewed journals and dissertations/theses were included.

Teacher Professional Growth for NOS and SI

Explicit and Reflective NOS Interventions

The studies that met inclusion criteria represent the plethora of evidence-based ER approaches used to improve teachers' NOS and/or SI conceptions, and in some cases, teaching practices. The overarching goals of this review were to identify which type of ER NOS approaches have been effective, identify common intervention components that contributed to these successes, and examine research methodologies employed across studies to evaluate the rigor of these interventions. To meet these goals, the Interconnected Model of Teacher Professional Growth (IMTPG) was used as an organizational framework to analyze features of the NOS ER approaches and the outcome variables identified within the 39 studies.

The IMTPG framework consists of four domains vital to the professional development of teachers: the external domain, the personal domain, the domain of practice, and the domain of consequences (Figure 2.1). Connections between domains represent how changes in one domain contribute to changes in an adjacent domain. Clarke and Hollingsworth (2002) identified reflection (represented by these connections between domains) as a key change mechanism in teacher professional growth, making this framework ideal to examine ER NOS interventions that are reflective in nature.

Changes can be traced in any direction through the framework and through multiple domains, and pathways of change provide a visual representation of teacher professional growth (see Clarke & Hollingsworth, 2002 as well as Chapter 4 for examples). The following section will describe the salient factors within each domain that emerged in the extant literature, as they might be responsible for teacher professional growth for NOS and SI specifically.

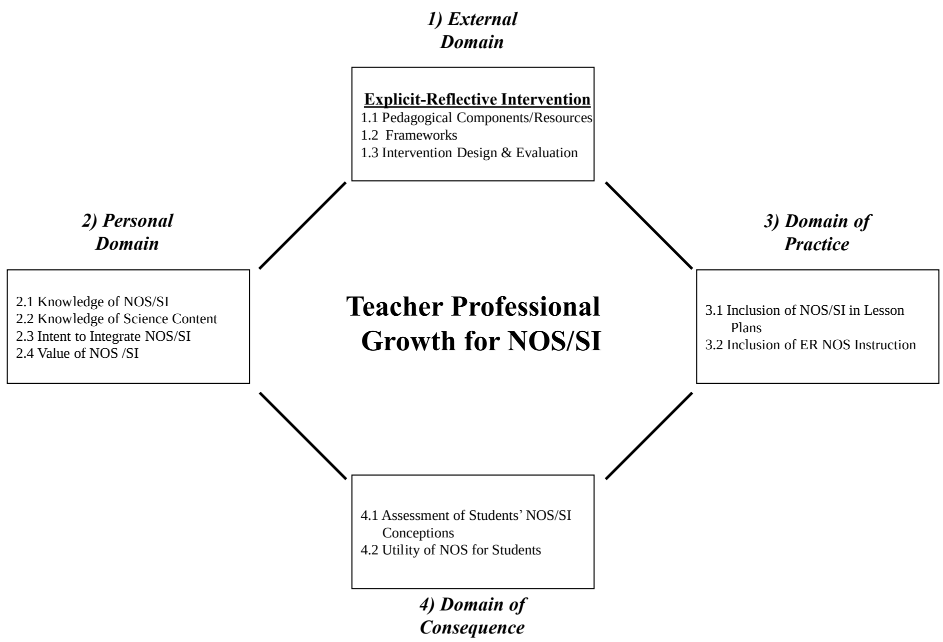

Figure 2.1. The Interconnected Model of Teacher Professional Growth with salient features and outcomes that emerged from ER NOS studies (see Appendix 2.A). Adapted from "Elaborating a Model of Teacher Professional Growth," by D. Clarke and H. Hollingsworth, 2002, *Teaching and Teacher Education*, 18, p. 951.

1. *External Domain*

The external domain includes any external stimuli outside the boundaries of the teaching environment that influence events that occur inside the classroom. The ER NOS interventions and salient components identified in the extant literature comprised the external domain within the analytic framework of this review. In order to delve further into this domain, components of interventions were examined, including: 1.1) common pedagogical approaches and resources identified, 1.2) common theoretical learning frameworks that guided the design of the ER approach, and 1.3) research methodologies and evaluation considerations associated with the ER approach (Figure 2.1). Looking at common pedagogical approaches allowed for comparison of the learning tools used in each intervention, and an examination of the frameworks assisted in understanding the learning theories that governed how those tools were used during professional development. Evaluation of study designs were also briefly synthesized and critiqued to contextualize the later discussion of research outcomes. These three components will be briefly discussed in the next sections.

1.1 Pedagogical Components of NOS ER Interventions

To begin the analysis, critical pedagogical components of the interventions used in the studies were examined. All 39 studies included in this literature review used one or a combination of pedagogical components and resources to support the ER NOS intervention. Typically, a combination of decontextualized and contextualized NOS activities were used (Table 2.2). The use of NOS activities not connected to specific science content, referred to as decontextualized NOS strategies, were the most often approach used with 33 of the 39 studies (85%) including at least one such activity as part of the intervention. These activities focused on developing familiarity with specific NOS aspects without the need for prerequisite science knowledge, making them ideal in situations where teacher-learners do not have a strong science background (Lederman &

Abd-El-Khalick, 1998). As an example, Akerson, Abd-El-Khalick, & Lederman (2000) specifically used decontextualized NOS activities to provide teachers with a framework for understanding NOS and to provide opportunities to reflect on NOS aspects. This was done during individual written reflections as well as whole-class discussions. Common decontextualized NOS activities used across studies were *Tricky Tracks*, *Young? Old?*, *Aging President*, the *Tube Activity*, and black box activities, among others (Clough, 1997; Lederman & Abd-El-Khalick, 1998; McComas & Olson, 1998).

The next most frequently used pedagogical component within ER NOS strategies was the use of contextualized NOS activities. These activities embed aspects of NOS in specific science content. A total of 25 studies (64%) used contextualized NOS activities. For example, Bloom, Bins, and Koehler (2015) contextualized NOS instruction using documentary films focused on historical scientific discoveries. Children's literature has also been used to provide a context for elementary teachers to learn NOS (Akerson, Abd-El-Khalick, 2000; Akerson, Hanson, & Cullen, 2007; Akerson et al., 2009; Lin et al., 2012). Embedding NOS activities within science content can facilitate learning by providing learners with a tangible referent in which to make sense of abstract NOS ideas (Schwartz, Lederman, & Crawford, 2004). While some studies used either decontextualized activities or contextualized activities independently, there is some evidence that using a combination of both types of pedagogical approaches is most effective to develop learners' NOS conceptions (Clough, 2006; Mulvey & Bell, 2016). Indeed, almost half of the studies in this review (48%) used some sort of a combination of these approaches.

The third most common resources used in ER NOS instruction were NOS readings (e.g., Myths of Science, Standards Documents, etc.) and historical case studies. Over half (56%) of studies incorporated one or both of these approaches. Other approaches, such as using metacognitive instruction, providing teachers with mentoring by a NOS expert, and engaging teachers in authentic research experiences have been used sporadically with some success. See Table 2.2 for a list of studies that utilized these less common intervention approaches.

Table 2.2

Frequency of Pedagogical Components and Resources Used Across ER NOS/SI Studies

Components & Resources	**Total Studies**	**%**
Decontextualized NOS Activities	33	85
Contextualized NOS Activities	25	64
NOS Readings	13	33
Historical Case Studies/NOS Cases	9	23
Authentic Research Experiences	7	18
Metacognitive Components	7	18
Extensive Mentoring in by NOS Expert	6	15
Children's Literature	4	10
Standards Documents	5	13
Ostention	4	10
Video Media	4	10
Create NOS Activities	2	5
Philosophy Readings	1	3

**Note.* Some studies used multiple pedagogical approaches so the 'Total Studies' column sums to more than the n = 39 examined in this review.

One final approach to NOS professional development stands out from the rest in that it did not focus specifically on the common NOS and SI aspects (Table 2.1) but focused on the general idea of what constitutes scientific knowledge. This approach was ostention, a process that requires learners to construct knowledge by differentiating key characteristics of concepts through the comparison of exemplars (Kuhn, 1974). Smith and Scharmann (2008) incorporated ostention into ER NOS instruction by asking teacher-learners to collaborate and come to consensus about the degree to which paired terms or phrases (e.g., genetics vs. computer science; humans have a soul vs. the rate of acceleration of all falling objects on earth is constant) were more or less reflective of the scientific endeavor. Their intervention used principles of ostention to focus learners by providing "prototypical examples and counterexamples, employing contrasting sets of these examples, and sequencing these examples from most prototypical to borderline cases" (p. 229). Bloom, Bins, and Koehler (2015) also used ostention in a similar manner, incorporating the prototypical examples and activities used by Smith and Sharman while at the same time using films as a context for NOS instruction. Others such as Bilican, Cakiroglu, and Oztekin (2015) and Demirdogen & Uzuntiryaki-Kondakci (2016) used variations of ostention as they engaged preservice teachers in NOS professional development. In all of these cases, ostention was helpful in promoting teacher professional growth for NOS.

1.2 Theoretical Frameworks Guiding ER Interventions

1.2.1 Conceptual Change for Teaching

In addition to the components of the interventions themselves, common theoretical learning frameworks emerged that were used to design and guide many ER NOS approaches. The two most common included conceptual change theory (Hewson, Beeth, & Thorley, 1998) and communities of practice theories (Lave & Wenger, 1991). We consider these common learning frameworks below and the studies that used them.

This is not an exhaustive explanation of these learning frameworks, merely a brief discussion that will allow the reader to align particular studies in this review to these learning theories in the context of NOS and SI.

Including conceptual change theory in future ER NOS interventions was a recommendation made by Abd-El-Khalick and Lederman (2000) and four studies directly applied this learning theory to ER NOS interventions. Akerson, Abd-El-Khalick, and Lederman (2000) and Abd-El-Khalick and Akerson (2004) embedded the four guidelines of conceptual change learning theory to identify factors that facilitated or impeded changes in elementary preservice teachers' conceptions of NOS and SI. Guidelines used to implement ER instruction included making student and teacher ideas about NOS an explicit part of classroom discourse, using pedagogical strategies (e.g., questioning, guided reflections, etc.) to ensure discourse was metacognitive, negotiating the status of NOS ideas, and justifying the status placement of NOS ideas (Hewson et al., 1998). Smith and Scharmann (2008) sought to determine the degree to which conceptual change occurred with secondary preservice teachers enrolled in a science laboratory course for teachers. Lastly, Ozgelen (2012) used a conceptual change model to determine the effectiveness of ER NOS instruction within the context of a science laboratory course to change preservice science teachers' NOS conceptions. Studies that incorporated a conceptual change framework all reported professional growth for teachers for NOS learning.

1.2.2 Communities of Practice

A total of nine studies (23%) used a community of practice framework (Lave & Wenger, 1991) to guide their ER NOS interventions. In these studies, providing teachers with structured time to come together and discuss NOS ideas with the support of a NOS expert was instrumental in helping teachers develop adequate NOS conceptions and teaching practices (Lederman et al., 2001). Interventions based on communities of practice also gave teachers time to share personal successes and failures experienced when implementing new ER NOS strategies recently learned in ER NOS professional development. One such study used a modified lesson study format to form a community of practice (Akerson, Pongsanon, Park Rogers, Carter, & Galindo, 2017). While 23% of studies focused on developing communities of practice for NOS, all of these were conducted by a single, common author. This indicates that while using a community of practice framework was a fairly common approach within the studies examined here, it is not a universal approach across multiple research teams.

1.3 Intervention Design & Evaluation

Up to this point I have discussed the tools and learning theories common across ER NOS interventions. The other domains of the IMTPG model often serve as the source of outcome variables in research studies, so before these other domains are reviewed it is worth examining the study designs that generated the outcomes from these interventions. Improving teachers' views of NOS is a complex and difficult endeavor (Abd-El-Khalick & Lederman, 2000). Therefore, it is vital that the research design of ER NOS interventions are carefully considered to provide sufficient information for evaluating their effectiveness.

Critical methodological considerations that arose in these studies are discussed below, such as determining whether changes in teachers' NOS views persisted over time (1.3.1), sample size of the study (1.3.2), the inclusion of a control or comparison group (1.3.3), the reporting of intervention effect sizes (1.3.4), the duration of the intervention (1.3.5), and whether design experiment methodology was used (1.3.6) (Table 2.3). Overall findings revealed that the evidence used to support the effectiveness of ER NOS strategies for promoting teacher professional growth consisted mainly of descriptive studies that relied on qualitative data sources. The most common assessment used to ascertain changes in NOS conceptions was the Views of Nature of Science (VNOS) questionnaire, with 85% of the studies using some version of this open-ended questionnaire followed by selective interviews to corroborate participants' written responses. Results from the VNOS were often used to create rich participant profiles to compare qualitatively after the completion of the intervention. Other less common data sources included classroom or professional development artifacts, focus group discussions, or classroom observations.

Table 2.3

Methodological Considerations for ER NOS/SI Studies

Methodological Considerations	Total Studies	Percentage of Studies
Long-Term Retention of NOS Views	4	10
Comparison or Control Group	4	10
Effect Size Reported	2	5
Design Experiment	1	3

1.3.1 Long-Term Retention of Views

The goal of most ER NOS interventions was to improve teachers' knowledge of NOS sufficiently so they could translate this knowledge into their teaching practices. Indeed, Mulvey & Bell (2016) argued if teachers are expected to translate NOS views they develop in professional development into their classroom practices, these views must be retained long-term. Only 10% of the 39 studies included a delayed post-test to determine whether teachers' NOS views persisted over time, and results from this handful of studies were mixed.

Akerson, Morrison, and McDuffie (2006) examined the effectiveness of using an ER NOS approach with preservice elementary teachers with one of the goals being to determine the long-term retention of NOS views. Preservice teachers' understandings of NOS were assessed pre, post, and 5 months after participation in a semester-long intervention embedded within a methods course. While teachers' NOS views improved pre- to post-intervention, the delayed post-assessment showed these views were not always retained long-term.

Akerson, Townsend, Donnelly, Hanson, Tira, & White (2009) embedded ER NOS instruction in a 2-week summer professional development for elementary teachers. Surveys, interviews, and classroom observations were used to track changes in teachers' views of NOS and SI after their participation in a summer modeling workshop. A subset of four teachers' views of NOS and SI were examined in detail over the course of the summer and then again during a school-year workshop a few months later. Teachers' views of NOS and SI improved when measured at the end of the summer workshop. However, while some of these changes remained intact when measured again during the school year, all the teachers held some mixed views of SI and NOS on the delayed post-assessment.

More recently, Wahbeh and Abd El Khalick (2014) conducted a study in Palestine in response to the need to prepare science teachers to meet the NOS objectives set forth in that country's national science standards. An integrated ER NOS approach was used in the context of a summer PD course for inservice teachers. The researchers measured pre and post changes after the integrated intervention. In addition, a post test was given 6 weeks after the completion of the study and then again after 5 months. Teachers' developed understandings of NOS improved over time and, unlike other studies, were retained when assessed 5 months after the study.

1.3.2 Sample Size

In addition to the methodological concerns with not conducting delayed posttests, there were also issues with the statistical generalizability of some studies based on limited sample sizes. The average sample size across all 39 studies was approximately 30 teachers, with studies reporting as low as n = 4 and as high as n = 236 participants (Figure 2.2). Only two studies included over 100 participants, and in most studies with over 30 participants, a smaller sub-sample of teachers was usually purposely selected and examined in depth, decreasing sample size further when examining the results. Although small sample sizes are not inherently bad in the context of many of the research designs used, these numbers do indicate a lack of an ability to generalize statistically across multiple representative populations.

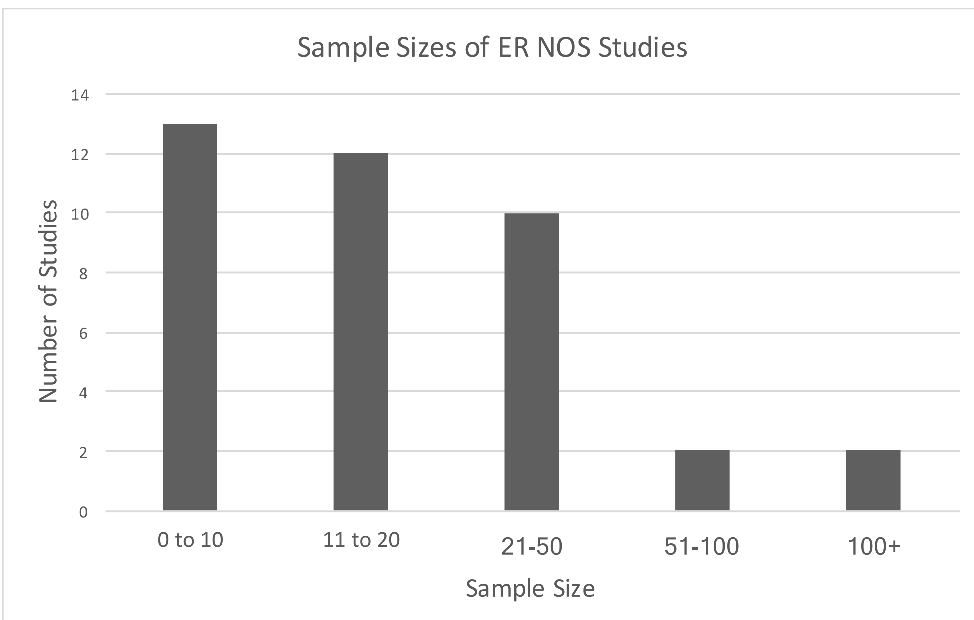

Figure 2.2. Summary of the number of participants (sample size) in ER NOS interventions by number of studies. *Note. One study in the 100+ category examined all subjects on some measures but conclusions were reported based on an in-depth examination of a subsample (n = 17).

1.3.3 Comparison or Control Groups

Another methodological pattern found among most of the ER NOS intervention studies was a lack of quasi- or true experimental designs utilizing a comparison or control group. Only four studies compared the effectiveness of using a NOS ER intervention to a control or comparison group. Each of these will be summarized briefly here for the potential importance of these studies to provide generalizable inferences of causality from the resulting data.

Abd-El-Khalick and Akerson (2009) examined whether preservice teachers who exhibited a deep processing orientation and used metacognitive strategies when engaged in ER NOS instruction were able to develop more sophisticated understandings of NOS than teacher-learners who did not. One preservice elementary methods course section was randomly selected to receive ER NOS instruction using three metacognitive strategies, while a comparison group only received typical ER NOS instruction. The three metacognitive strategies used were concept mapping, assisting researchers in tracking the NOS idea development of their peers, and case studies. While both groups' views of NOS aspects improved, the intervention group's understanding of NOS aspects was statistically significantly greater than the comparison group's at the end of the intervention. Because a comparison group was used, there is some generalizable evidence that ER approaches that incorporate metacognitive strategies are likely to be more effective than stand-alone ER NOS instruction.

Lin, Lieu, Huang, and Chang (2012) developed and evaluated how training teachers to use researcher-created teacher guides for integrating NOS aspects into inquiry instruction influenced teachers' NOS understandings, pedagogical content knowledge (PCK), beliefs and intent to teach NOS, as well as students understandings of NOS. A total of 10 teachers were grouped based on their prior NOS knowledge; six teachers possessed informed knowledge about NOS while four teachers held naive views. Each group received training on using educative NOS teaching guides but results showed that using guides spurred changes in teachers' professional growth for NOS regardless of teacher prior knowledge.

The study mentioned previously by Wahbeh & Abd El Khalick (2014) also incorporated a comparison group by randomly assigning a subset of six middle and high school teachers from the larger study to one of two comparison groups. One group (n = 3) received extensive support by the researchers as teachers attempted to include NOS in their teaching, while the other group (n = 3) did not receive support. This enabled the researchers to determine to what extent support by a NOS expert influenced professional growth for NOS. Findings from this study indicated that teachers struggled to translate their newly-developed NOS understandings into their classroom instruction despite having extensive support. Note that despite random assignment to groups, there remains the sample size concerns indicated in the previous section.

The final ER NOS study that used comparison groups was conducted by Pekbay & Ylimaz (2005). Preservice elementary teachers enrolled in an environmental education course were randomly assigned to receive ER NOS instruction or NOS instruction through historical case studies. Teachers assigned to the ER NOS condition scored statistically significantly higher on post NOS assessments for some NOS aspects, providing some evidence that ER NOS instruction was more effective. However, because there was no group that received only typical instruction in the environmental science course, it is unknown whether similar changes on NOS assessments would have occurred regardless of the two NOS instructional approaches used. Despite this, what these four studies have in common is the use of research designs that attempted to assess and measure causality of variables in ER NOS interventions on teachers' NOS understandings.

1.3.4 Effect Size

In addition to limited studies inferring causality with quasi-experimental research designs, few studies moved beyond reporting descriptive results and very few documented the practical significance of the intervention. The practical significance of an intervention can be reported using an effect size metric, usually the standardized mean difference between outcome scores for the treatment and control conditions (Cohen, 1988). Similar to medical impact studies, reporting effect sizes in educational research is becoming more common, as the value of this metric has become increasingly important (Lipsey, 2012). Only four ER NOS studies included some type of comparison or control group (Abd-El-Khalick & Akerson, 2009; Lin et. al., 2012; Pekkbay & Yilmaz, 2015; and Wahbeh & Abd-El-Khalick, 2014), and of these, only Lin et al. (2012) reported an effect size to show mean differences between the two comparison groups.

Effect sizes can also be calculated to show pre-post mean differences within one group of participants who received an intervention. Burton (2013) did not include a comparison group when examining the effect of an ER NOS intervention that used teacher-participants' student work products. However, teachers' Views of Science Education (VOSE) survey scores from before and after the intervention were compared and Cohen's d effect size was reported for teachers' professional NOS growth on individual aspects.

1.3.5 Duration of Intervention

Another methodological pattern noted among studies was that many were relatively short in duration (Figure 2.3). The exception was the ICAN project (one year) and the study by Lederman et al., (2001) which spanned an entire master's degree program (Figure 2.3). In line with recommendations by Timperly et al., (2007) and others, professional growth for PCK likely requires longer interventions, such as those provided by the ICAN Project or Lederman et al., (2001).

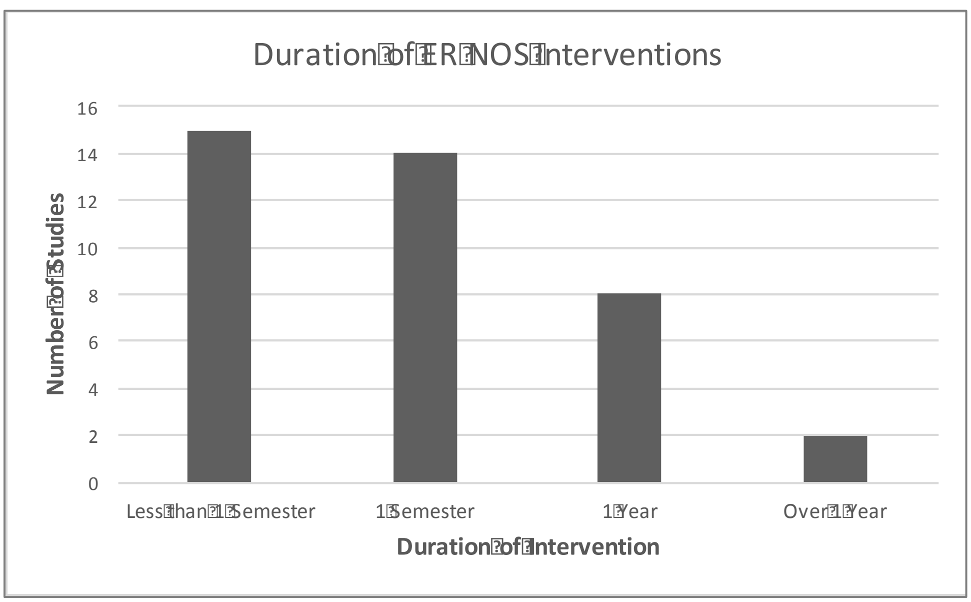

Figure 2.3. Intervention duration for ER NOS intervention studies by the number of sampled studies.

1.3.6 Design Experiments

Moving away from more quantitative methodological considerations such as sample size, experimental designs, and effect size statistics discussed above, this section considers a more qualitative methodological aspect. The goal of most intervention research in education is to inform teaching practices, making it important that what is deemed as an "effective" intervention can be implemented in the context of a real classroom (Brown, 1992). Design experiments provide an ideal approach for evaluating the effectiveness of educational research because the methodology takes into consideration the complexity inherent to educational settings (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003).

No ER NOS intervention examined in this literature review described their approach explicitly as a type of design experiment, although the study by Lederman et al. (2001) was based on three iterations of essentially the same study and could be considered a design study. The findings from this research groups' previous results indicated that to help preservice teachers translate NOS knowledge into practice, NOS content instruction should be separated from teaching NOS pedagogical approaches (Abd-El-Khalick et al., 1998) and that it was important that teachers internalized the need to treat NOS as content to be planned for and assessed (Bell et al., 2000). Therefore, the ER approach they implemented spanned an entire year of preservice teacher coursework and experiences and was much more extensive that typical NOS ER interventions. An entire course was dedicated to NOS, inquiry experiences were purposely designed to make explicit NOS and SI aspects in the context of science, participants were required to create resource cards that described ways NOS and SI aspects would be relevant to their teaching, and preservice teachers were asked to develop NOS objectives and student assessments both in their coursework and during their teaching practicum.

Table 2.4

Theoretical Frameworks and Methodological Considerations Across Studies

	Conceptual Change Theory	Community of Practice	Retention of NOS Views	Comparison or Control Groups	Design Research	Effect Size Reported
Total Studies (n = 18)	4	9	4	4	0	2
Akerson, Cullen, & Hanson (2009)		x				
Akerson & Hanuscin (2007)		x				
Peters Burton (2013)						x
Akerson et al., (2009)		x	x			
Abd-El-Khalick & Akerson (2004)	x	x				
Akerson, et al., (2000)	x					
Akerson, Hanson, & Cullen (2007)		x				
Akerson, et al., (2006)			x			
Smith & Scharmann (2008)	x					
Lederman et al., (2001)		x				
Pekbay & Yilmaz (2015)				x		
Abd-El-Khalick & Akerson (2009)				x		
Ozgelen et al., (2013)		x				
Ozgelen (2012)	x					
Wahbeh & Abd-El-Khalick (2014)			x	x		
Akerson, et al., (2012)		x				
Mulvey & Bell (2016)			x			
Lin et al., (2012)				x		x
Akerson et al., (2017)		x				

*Note. Only studies that included at least one of the theoretical frameworks or methodological considerations were included in this table.

2. Personal Domain

The personal domain in the IMTPG framework includes any characteristic of the teacher they bring with them into their classroom practice, such as personal beliefs, values, attitudes, and content knowledge, among others. Four main personal characteristics thought to be related to whether teachers will develop sophisticated NOS conceptions emerged from the review of the literature (Figure 2.4): 2.1) knowledge of NOS/SI, 2.2) knowledge of science content, 2.3) intentions to integrate NOS/SI, and 2.4) whether teachers valued NOS as an instructional outcome. A brief description of how studies addressed these personal characteristics and the frequency with which studies included them will be described next.

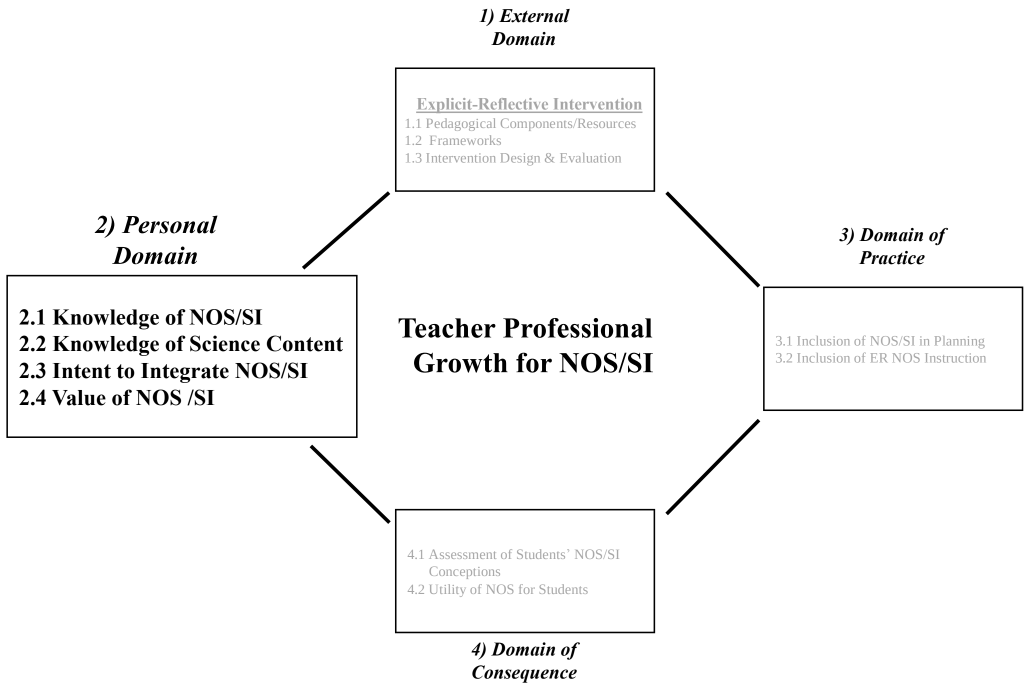

Figure 2.4. Four factors within the IMTPG personal domain thought to be related to teacher professional growth for NOS and SI.

2.1 Knowledge of NOS and SI

All ER NOS interventions included in this review aimed to develop teachers' knowledge of NOS using various combinations of pedagogical approaches and resources to accomplish this primary goal (Table 2.5). Regardless of the context in which the study took place or the characteristics of the participating teachers, teacher-learners' knowledge of NOS improved when teachers engaged in ER NOS instruction. However, the degree of changes observed varied across studies and rarely did all teachers in an intervention study develop sophisticated views of NOS for all aspects. Therefore, some studies attempted to identify potential mediating factors that might explain inconsistencies in results.

2.1.1 Mediating Factors

Lederman et al., (2001) and Abd-El-Khalick & Akerson (2004), among others, postulated that developing teachers' knowledge of NOS was difficult and varied across studies because yet unexplored mediating factors were likely at play. These include conceptual, affective, and motivational factors, as well as those inherent to social and cultural values (e.g., religious views). Identifying mediating factors involved in whether and to what extent teacher professional growth for NOS occurs, specifically when attempting to change teachers' naïve NOS conceptions, was explored by some studies included in this review.

For example, Akerson, Buzzelli, and Donnelly (2008) sought to determine whether a relationship existed between early childhood (K-3) preservice teachers' NOS views and intellectual development as measured using Perry's Scheme (Perry, 1970). Results showed that those participating teachers who identified at a higher level on Perry's Scheme held more informed NOS views.

In another representative study, Smith and Scharmann (2008) used an ER NOS intervention at a university where students held conservative, religious views. By taking religious views into account, the researchers successfully changed preservice teachers' NOS conceptions to be more congruent with science education reform standards. Much more research needs to be conducted on factors mediating the changes in NOS views, however, what is consistent across all studies conducted is that NOS views can be changed.

2.1.2 Knowledge of NOS Aspects

Universally, across all 39 studies, teachers who engaged in ER NOS interventions showed improved NOS understandings. However, this varied for particular NOS aspects (Table 2.1) indicating that some aspects may be more resistant to change than others (Mesci & Schwartz, 2017). For example, Pekbay and Yilmaz (2015) found statistically significant differences in NOS understanding between two groups when ER NOS instruction was compared to historical NOS instruction. When the results were examined discreetly by particular NOS aspects, there were no statistically significant differences between groups for understandings for the following NOS aspects that science is empirically based, tentative, requires imagination or creativity, or the distinction between a theory and law. There were, however, statistically significant differences for the NOS aspects of subjectivity in science and how observations and inferences are used in science.

In another representative study, Mesci and Schwartz (2017) examined changes in preservice teachers NOS views after completing a NOS course. As hypothesized, preservice teachers' NOS conceptions improved, but less growth was observed for the NOS aspects of tentativeness, socio-cultural embeddedness of scientific knowledge, and the differences between theory and law. Other researchers have also indicated teachers' understandings differentially improved for some NOS aspects but not for others (Demirdogen & Uzuntiryaki-Kondakci, 2016; Kucuk, 2008; Mulvey & Bell, 2016). Closer examination of which aspects are more resistant to change, for whom and under what conditions and why, is an area of inquiry that could be explored further but is currently beyond the scope of this review.

2.2 Knowledge of Science Content

As described in the previous sections, factors such as intellectual development and religiosity may mediate developing NOS understandings. These teacher characteristics are difficult to address in professional development, but one factor important in the development of teachers' NOS understandings that can be addressed is science content knowledge. Therefore, including science content alongside ER NOS instruction may facilitate teacher professional growth for NOS (Wahbeh & Abd-El-Khalick, 2014). Just under 40% (15/39) of the studies included explicit instruction in a specific content area (e.g., biology, physics, chemistry) aligned with the ER NOS intervention. Lederman, Schwartz, Abd-El-Khalick, and Bell (2001) embedded ER NOS instruction throughout an entire master's degree program for science teachers, ensuring they would receive NOS instruction concurrently with their science content courses. This long-term, NOS-focused program facilitated teacher professional growth for NOS.

Morrison, Raab, and Ingram (2009) immersed secondary and elementary teachers in an authentic science setting where the participants shadowed scientists at the Laser Interferometer Gravitational Wave Observatory and engaged them in conversations about their work as well as their views about science (NOS). The goal of the intervention was to surround teachers with examples of NOS in an authentic science setting, and encourage them to spend time reflecting on the processes and knowledge generated by scientists. This experience enabled elementary and middle school teachers who had little research experience to develop more sophisticated NOS views.

Some interventions may have purposely failed to include science content instruction aligned with NOS instruction to focus time and resources exclusively on NOS, knowing teachers would likely receive science content instruction in other settings. However, deep conceptual understanding of science content knowledge is likely necessary for teachers to integrate newly acquired NOS conceptions into their existing knowledge structures (Wahbeh & Abd-El-Khalick, 2014). This calls into question whether teachers who may lack high levels of science content knowledge can develop sophisticated understandings of NOS in a professional development setting that does not provide at least some degree of science content instruction. Indeed, Rudge, Cassidy, Fulford, and Howe (2014) found that a major contributing factor in the development of preservice elementary teachers' NOS understandings was their ability to generate examples from science to contextualize NOS aspects. This supports the idea that deep, conceptual science content knowledge may be necessary for teachers to develop sophisticated NOS conceptions.

2.3 Intent to Integrate

In addition to teacher knowledge, other factors that emerged from the literature as salient to teacher professional growth (in the IMPTG personal domain) included teachers' values and beliefs regarding NOS. Therefore, intentions teachers have to integrate NOS into teaching practice and whether NOS is a valued construct in their classrooms are included within this domain. Some consideration of a teacher's intent to integrate NOS instruction was identified in approximately 20% (7/39) of the ER NOS studies reviewed.

Some studies approached their intervention with the idea that teachers' intentions toward NOS (e.g., integration of NOS in instruction) was important to consider when evaluating the outcomes of the intervention. This was apparent in the study by Lederman, Schwartz, Abd-El-Khalick, and Bell (2001) that emphasized the importance of NOS throughout the duration of a master's program for preservice teachers. The design of the study revolved around the assumption that teachers' intentions regarding NOS integration was a keystone component that mediated the translation of NOS knowledge to teaching practices.

Some studies included a measure to determine whether their ER NOS intervention influenced teachers' intentions for NOS. Donnelly and Argyle (2011) explicitly assessed participant teachers on how they intended to include NOS in their future classroom practice while Mulvey and Bell (2016) examined teachers' motivation and rationales for including NOS in their classroom practice. Results suggested that after developing sophisticated NOS conceptions, the next most important factor for teachers to translate NOS knowledge into practice is to value NOS enough to integrate it into their science instruction. This was supported by other studies, such as Kucuk's (2008) work with Turkish elementary preservice teachers and in a study by Buaraphan (2012). At the conclusion of each respective study, both researchers reported that teachers' beliefs that NOS should be integrated in instruction had changed and that this was vital if they were to translate recently developed NOS knowledge into teaching practices.

2.4 Value of NOS

Closely tied to intentions of teachers to integrate NOS instruction in their practice is the value they place on NOS as a learning objective in their classrooms. Fewer studies (3/39) considered the value teachers place on NOS as a part of teacher professional growth. As an example, Mulvey and Bell (2016) reported that teachers can only begin to value NOS as they began to understand and recognize how it supported their students' understandings in science. Indeed, some participants in their ER NOS intervention indicated they "planned to teach NOS because they now understood it" (p. 15).

What is clear from all these studies is that in order for teachers to intend to implement NOS instruction in their own practice they must have an understanding of NOS, how it supports the science content they teach, and value it enough to want to implement it. It is with this notion that I transition to studies that have examined how teachers implement NOS instruction in their classrooms following a professional development intervention.

3. Domain of Practice

The domain of practice within the IMPTG framework includes any pedagogical decisions, planning, and approaches used by the teacher directly or indirectly in their classroom instruction. Two main factors that resided in the domain of practice related to NOS instruction emerged from the literature: 3.1) whether a teacher included NOS in their lesson plans, and 3.2) whether a teacher attempted to include ER NOS instruction in their classroom practice. Brief descriptions of which ER NOS interventions facilitated teachers inclusion of NOS planning and instruction are briefly described next.

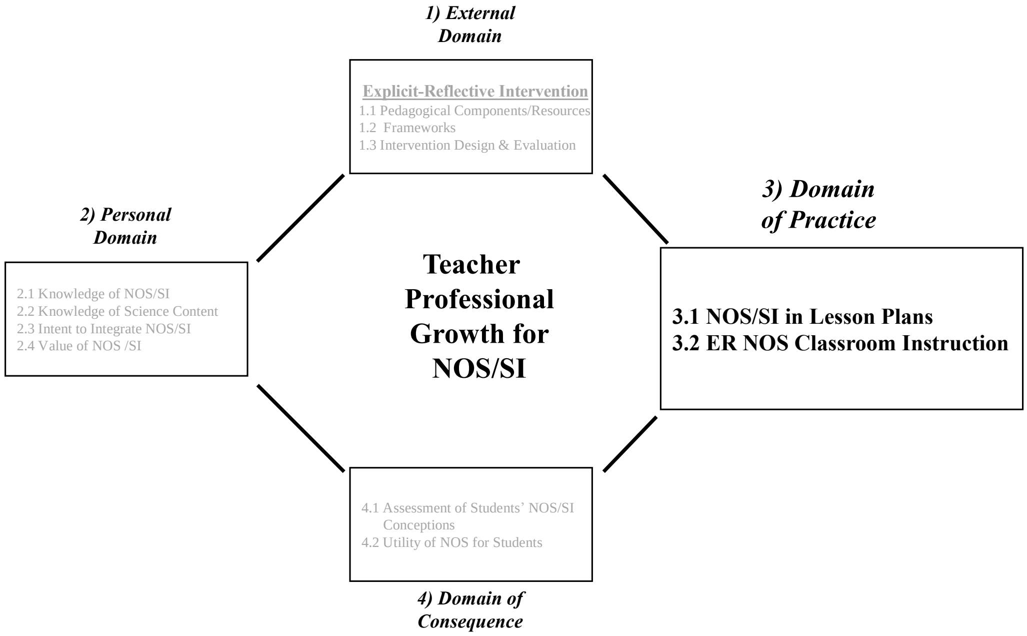

Figure 2.5. Two factors within the IMTPG domain of practice thought to be related to teacher professional growth for NOS and SI.

3.1 Inclusion of NOS/SI in Planning

The long-term goal of ER NOS interventions for teachers is to enable them to effectively include ER NOS instruction in their science classrooms (Lederman, 1999). Teachers must plan how they will incorporate NOS into their classroom first by writing learning objectives and lesson plans (Akerson, et al., 2017) before they can even begin to think about effectively implementing this difficult instructional objective. Approximately 56% of ER NOS interventions (22/39) included having teachers develop lesson plans with specific learning objectives to target students' NOS and/or SI conceptions.

Bilican, Cakiroglu, and Oztekin (2015) used ER NOS instruction in a methods course that required preservice elementary teachers to prepare lesson plans and share how they would include NOS in their future classroom practice. Not only did this provide teachers with the opportunity to reflect on how they would include NOS in their teaching, it also gave them the opportunity to refine their newly developed NOS conceptions. Teachers engaged in whole-class discussions about their lessons which enabled them to "revisit their NOS concepts which resulted in deeper understanding of those NOS aspects" (p. 484).

In another study, Wong et al. (2016) required inservice middle school science and mathematics teachers to write lessons plans for NOS as a part of an online NOS Master's program. Teachers were expected to use these lesson plans to reflect on their own classroom practices for including NOS. Using lesson plans to reflect on NOS resulted in improved NOS conceptions for these science and mathematics teachers. In a study conducted by Demirdogen and Uzuntiryaki-Kondakci (2016), preservice chemistry teachers critiqued contrasting NOS lesson plans where one plan addressed NOS implicitly while the other used an explicit and reflective approach. Participants were required to create two lesson plans, one prior to critiquing existing NOS lesson plans and one after. Lesson plans created after the intervention indicated that participants were able to include at least one NOS aspect in their lessons and saw NOS as a cognitive outcome to be planned for, integrated into chemistry instruction, and assessed. Other studies included lesson plan preparation as a way to make NOS explicit and reflective component in their ER NOS intervention.

3.2 Inclusion of ER NOS Instruction

While NOS knowledge improved across all studies, when teachers prepared lesson plans with the explicit intent to integrate NOS *and* received extensive support by NOS experts, the frequency with which NOS was included in classroom instruction and quality of this instruction were inconsistent. A total of 10 studies (26%) aimed to have teachers use ER NOS instruction in K-12 science classrooms and describe outcomes from these studies. The following section will describe the degree to which teachers were successful in implementing ER NOS instruction.

3.2.1 Variation in Effectiveness

Teachers' ability to effectively incorporate ER NOS instruction following professional development varied across studies. Lederman et al. (2001) noted that previous ER NOS interventions had resulted in teachers only sporadically including NOS, if at all. The authors designed an intervention that focused both on assisting teachers to integrate NOS learning objectives *and* internalize NOS as an important instructional objective. The focus on NOS spanned an entire master's program and seven teachers participated in a study to determine the effectiveness of the ER NOS intervention. Using classroom observations, lesson plans, and interviews, results showed that all but one teacher included some type of ER NOS instruction in their classrooms. However, the frequency and depth of ER NOS instruction was highly varied. Of note was that teachers reported that they felt NOS was sometimes too abstract to include in secondary schools and that there was not enough instructional time with students to always integrate NOS.

Akerson, Donnelly, Riggs, & Eastwood (2012) focused on helping teachers transfer existing sophisticated NOS views into explicit teaching practices. Teachers participated in focus groups during their teaching internship and were observed teaching at least five times over the course of 10 weeks. Results showed that teachers included NOS explicitly in their lessons, but the extent to which NOS was included varied among teachers and for some, implementation seemed to wane as the semester progressed. In a similar study, Akerson, Cullen, and Hanson (2009) supported teachers using a community of practice model as they attempted to use ER NOS instruction in their elementary classrooms. Teacher success was mixed with six teachers including ER NOS instruction often, six including it sometimes, and three not including it at all during the school year.

Lotter, Singer, and Godley (2009) provided preservice secondary teachers with multiple opportunities to explicitly address NOS and SI in their teaching practicum and examined the pedagogical approaches the teachers used to address NOS and SI. Overall, preservice teachers struggled to incorporate NOS knowledge into their lessons. However, Lin et al., (2012) reported that training teachers to use NOS teaching guides enabled teachers to include NOS in their classroom instruction. Analysis of videotaped teachers' lessons using the NOS Teaching Observation Protocol scores indicated all teachers were able to satisfactorily include NOS in their teaching.

3.2.2 Extensive Support & Feedback for NOS Implementation

Due to the varied nature of implementation of NOS instruction following NOS interventions, it is important to consider what factors in the literature have demonstrated successes for teacher implementation of NOS. One factor that was found to help teachers when they attempted to integrate NOS was for experts to provide extensive support and feedback to teachers as they practiced using ER NOS instructional approaches (Akerson & Hanuscin, 2007; Akerson, Hanson, & Cullen; Akerson, et al., 2009; Mesci & Schwartz, 2017; and Akerson et al., 2017). Results from the Project Inquiry, Context, and Nature of Science project (ICAN, 2006) showed that providing teachers with opportunities to practice microteaching lessons and receive feedback shifted instruction from implicitly addressing NOS to addressing NOS more explicitly in their classroom teaching.

In a study by Wahbeh and Abd El Khalick (2014), six of 19 teachers in the study were purposely selected to be observed in their classrooms to determine the extent to which the PD influenced their teaching practices for NOS. The group of six was split into two groups, one which received extensive feedback and support from the researchers and the other that did not. Teaching practices were assessed from video recordings, researcher field notes, classroom observations, and teacher-researcher discussions. Teachers in the group that received support were more successful at incorporating NOS instruction while teachers in the group that did not receive support used some decontextualized NOS activities, but overall were not able to connect these activities to the science content they were teaching. Findings also revealed all teachers faced three major challenges when trying to integrate NOS instruction: 1) a lack of deep, conceptual content knowledge necessary to integrate NOS, 2) a lack of expertise in inquiry-based pedagogy, and 3) a struggle to create new NOS activities to integrate into their classroom.

A professional development approach used to provide teachers with extensive support and feedback is lesson study (Stigler & Hiebert, 1999). Akerson, et al., (2017) examined whether a modified lesson study approach could facilitate the transfer of NOS knowledge into teaching practice. Six preservice teachers participated in a lesson study in the context of a methods course. They were given opportunities to collaboratively plan, teach, and reflect on their practice during the field placement portion of the course. Teacher pairs worked together to create and teach a lesson while the other four pairs observed. Afterward, they engaged in lesson study to discuss whether ER NOS instruction occurred in their respective classrooms and how to modify future lessons. Results showed that despite multiple iterations of observing, discussing, and revising, these preservice teachers were only able to give suggestions about how others could integrate NOS more effectively and in most cases, they were unable to include ER NOS instruction in their own lessons.

Despite extensive support by NOS experts in the studies described above, some teachers were unable to effectively integrate ER NOS instruction into classroom instruction. For decades science teacher educators have known that there are numerous mediating factors and situational variables that likely determine whether teachers will successfully translate NOS knowledge into ER NOS instruction with their students (Lederman, 1992; Lederman et la., 2001). These include, among others, pressure to cover science content, standardized testing, concerns about classroom management, not having sophisticated NOS conceptions, and few classroom resources (e.g., activities and assessments) to include NOS (Abd-El-Khalick & Lederman, 2000). This confirms that implementing NOS in the classroom is not a simple task and conducting research into teacher professional growth will require consideration of multiple, interacting variables.

4. Domain of Consequence

The domain of consequence within the IMPTG framework consists of the salient outcomes desired by the teacher, such as appropriate student behavior, student understanding of content, or increases in student motivation. For teacher professional growth for NOS and SI, two factors emerged from the literature as important components within the domain of consequence: 4.1) the assessment of students' NOS conceptions and 4.2) how teachers see NOS instruction for students as important (utility of including NOS instruction). These will be described briefly in the next sections.

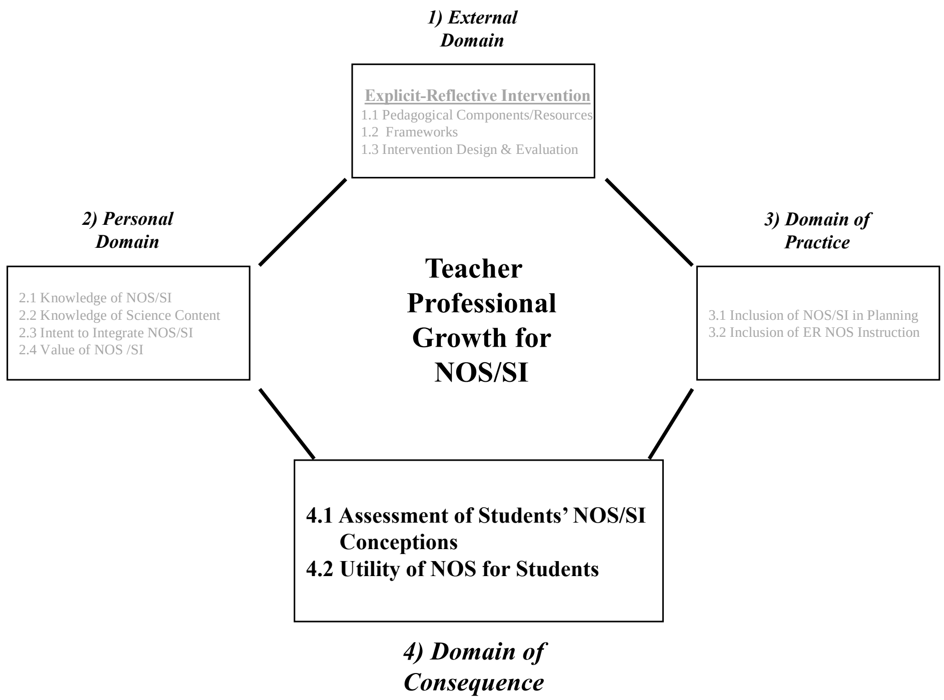

Figure 2.6. Two factors within the IMTPG domain of consequence thought to be related to teacher professional growth for NOS and SI.

4.1 Assessment of Students' NOS Conceptions

A total of six studies (15%) included some form of authentic student NOS or SI assessment as a component of the research study into teachers' professional growth for NOS or SI. In some studies, preservice teachers in methods courses were required to conduct interviews with elementary students to better understand students' views about science topics, including aspects of NOS. Preservice teachers then used these interviews to develop lesson plans to target students' alternative NOS ideas (Akerson & Abd-El-Khalick, 2004; Akerson, Buzzelli, & Donnelly, 2008). In other studies, students' NOS views were assessed to determine whether the ER NOS intervention with teachers influenced their students' views (Akerson & Hanuscin, 2007; Lin et al., 2012).

In other instances, students' understanding of NOS was not assessed but remained a focus of the professional development. For example, teachers grappled with how to best assess their own students' views (e.g., exam questions) to inform their NOS instruction (Akerson et al., 2017; Lederman et al., 2001). In another ER NOS intervention, Burton (2013) used student work products as a means to promote teacher reflection on the NOS. Teachers reflected on their students' work regarding NOS. Results showed that teachers were disappointed in students' performance and level of thought, conveying the importance of using an explicit approach to teaching NOS to their students.

4.2 Utility of NOS for Students

There is consensus in the K-12 science education community that NOS is vital to the development of a scientifically literate citizenry (Bybee, 1997; Driver, Leach, Millar, & Scott, 1996). Recent science reform documents stress understanding the nature of scientific knowledge is an important goal in the development of a scientifically literate populous. (Lead States, 2013). However, only one study included in this review explicitly reported teachers' rationales for integrating NOS in light of how understanding this construct would be useful to students as an outcome of their NOS instruction (Mulvey & Bell, 2016). Middle school teachers participating in an ER NOS professional development program said NOS would support students' in becoming scientifically literate, make science more relevant and engaging, and help students develop a general appreciation for science. In addition, some teachers thought that integrating NOS would help students develop critical thinking skills and possibly reduce intolerance as students learned the value of differing perspectives.

The past two decades have provided researchers with an enormous repository of rich, descriptive information regarding how teachers' think about the NOS and SI, and the factors involved in teacher professional growth for these constructs. The Views of Nature of Science [VNOS] (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002), Views of Scientific Inquiry [VOSI] (Schwartz, Lederman, & Lederman, 2008) and the Views About Scientific Inquiry [VASI] (Lederman et al., 2014) questionnaires (among others, see Abd-El-Khalick, 2014, p.624-625 for a complete list of NOS and SI assessments) have been pivotal in this progress and have provided researchers with a means to assess and report changes in NOS and SI views that occur in response to ER NOS interventions. Indeed, the majority of the studies included in this review used the VNOS or VOSI questionnaires to document teachers' professional growth for NOS and/or SI understandings. It is from this research that the pedagogical approaches for changing NOS conceptions were developed (Table 2.5) and factors thought to mediate changes in teacher professional growth (e.g., depth of teachers' science content knowledge, mentorship and support from NOS experts, access to NOS resources, etc.) were identified. If not for this work, the development of ER NOS interventions would not have been possible.

Table 2.5

Common Pedagogical Components within Studies

	Contextualized	Decontextualized	Authentic Research	Historical Case Studies	Metacognitive	Children's Literature	Video Media	Standards Documents	NOS Readings	Philosophy Readings	Mentored by Expert	Ostention	Create NOS Activities
Akerson, et al. (2008)	x	x		x			x						
Akerson, et al. (2009)		x					x						
Akerson & Hanuscin (2007)		x									x		
Bloom, et al. (2015)	x	x					x		x			x	
Peters Burton (2013)	x	x			x								
Donnelly & Argyle (2011)	x	x											
White (2010)		x	x										
Morrison, et al. (2009)	x	x	x		x		x		x				
Akerson et al. (2009)	x					x					x		
Project ICAN (2001-2005)	x	x	x								x		
Abd-El-Khalick et al. (2004)		x						x					
Akerson, et al. (2000)		x		x		x		x	x				
Akerson, et al. (2007)		x				x		x			x		
Akerson, et al. (2006)		x						x	x				
Seung, Bryan, & Butler (2009)	x	x			x								
Smith & Scharmann (2008)	x			x					x			x	
Lotter, Singer, & Godley (2009)		x						x	x				
Lederman, et al. (2001)	x	x	x								x		
Mesci & Schwartz (2017)	x	x	x	x					x		x		
Pekbay & Yilmaz (2015)		x							x				
Kucuk (2008)		x											x
Ornek & Turkey (2014)		x											
Abd-El-Khalick et al. (2009)		x	x	x	x				x				
Ozgelen, et al. (2013)	x	x							x				
Wahbeh et al. (2014)	x	x		x	x								x
Akerson, et al. (2012)	x	x											

Table 2.5 continued

	Contextualized	Decontextualized	Authentic Research	Historical Case Studies	Metacognitive	Children's Literature	Video Media	Standards Documents	NOS Readings	Philosophy Readings	Mentored by Expert	Ostention	Create NOS Activities
Mulvey & Bell (2016)	x	x											
Wong, et al. (2016)	x								x				
Ozgelen, et al. (2013)	x	x							x				
Bilican, et al. (2015)	x	x			x							x	
Cakmakci (2012)		x	x										
Buaraphan (2012)	x	x											
Kattoula (2008)	x			x									
Ozgelen (2012)	x	x		x					x				
Demirdogen et al. (2016)	x	x			x							x	
Lin et al. (2012)	x					x							
Rudge, et al. (2014)	x												
Abd El Khalick (2005)		x		x						x			
Akerson et al., (2017)	x	x									x		

Discussion

The overarching goal of this review was to examine ER NOS interventions used over the past two decades to identify factors that have contributed to teacher professional growth for NOS and SI and those that still need further examination. Numerous studies have evaluated the effectiveness of ER NOS interventions, and science teacher educators have incorporated combinations of pedagogical approaches to improve teachers' conceptions and practices regarding NOS and SI. In general, the main focus of these interventions has been on developing teachers' knowledge of NOS (personal domain) with the long-term goal of helping teachers translate this knowledge into their teaching practice (domain of practice). However, despite extensive efforts by science teacher educators (external domain) to change teachers' NOS understandings through combinations of pedagogical strategies, only in rare cases did teachers develop sophisticated NOS views across all aspects and only rarely were these changes observed long-term. The following sections will address recommendations for each professional growth domain based on the literature review. This will also include factors of ER NOS interventions that reside in the external domain.

Personal Domain

The question remains how to best facilitate teacher professional growth in the IMTPG personal domain to enable teachers to develop deep, conceptual knowledge structures for NOS and SI that can be translated into classroom practice (Bartos & Lederman, 2014). The studies examined in this review focused on several IMTPG personal domain variables, such as knowledge of NOS, knowledge of science content, intentions to integrate NOS in classroom instruction, and the value teachers' placed on NOS as an instructional outcome. Two additional factors within the personal domain were noticeably absent. The first was teacher-learners' science teaching orientations (Friedrichsen, van Driel, & Abell, 2011). Only Demirdogen & Uzuntiryaki-Kaondakci (2016) examined the influence of an ER NOS intervention on orientations, or included beliefs and/or orientations in any part of the study design. Second, few studies included explicit mention or assessment of teachers' NOS PCK. This is likely due to the complex nature of NOS PCK, as noted by Wahbeh & Abd-El-Khalick (2014) in their study that focused on documenting teachers' NOS PCK. Indeed, developing teachers' PCK for

NOS is an endeavor that has proven quite difficult, as effectively integrating NOS into science instruction requires teachers to have more than superficial NOS understandings and science content knowledge (Abd-El-Khalick & Lederman, 2000). Future ER NOS intervention studies may be strengthened by including measures of science teaching orientations or NOS PCK to document changes in either of these constructs after ER NOS interventions.

Domain of Practice

Over half of the ER NOS interventions examined in this synthesis examined factors situated in the domain of practice (22/39, 56%), with only a small portion of these studies (10/39, 26%) examining teachers' attempts at including ER NOS instruction in their own classrooms. These studies revealed that teachers struggled to include ER NOS and SI instruction in K-12 science classrooms, even with extensive support and training. This indicates the existence of an impenetrable barrier around the IMTPG domain of practice, preventing holistic professional growth for NOS and SI (Figure 2.7). The barrier represents inability of teachers, both inservice and preservice, to effectively transfer knowledge of NOS and SI into their classroom practice. ER NOS interventions have had some success improving conceptions, but we must ask why the barrier still exists after two decades of research on facilitating teacher professional growth for NOS? What steps are necessary for NOS science teacher educators to remove barrier? In a best evidence synthesis, Timperley, Wilson, Barrar, and Fung (2007) reported that for teacher professional development to be successful, teachers need extended time and multiple opportunities to engage in new pedagogical content and strategies. A majority of the ER

NOS interventions (74%) in this review took place for one semester or less. In regards to the duration of interventions, little has changed since 2000 (Abd-El-Khalick & Lederman, 2000).

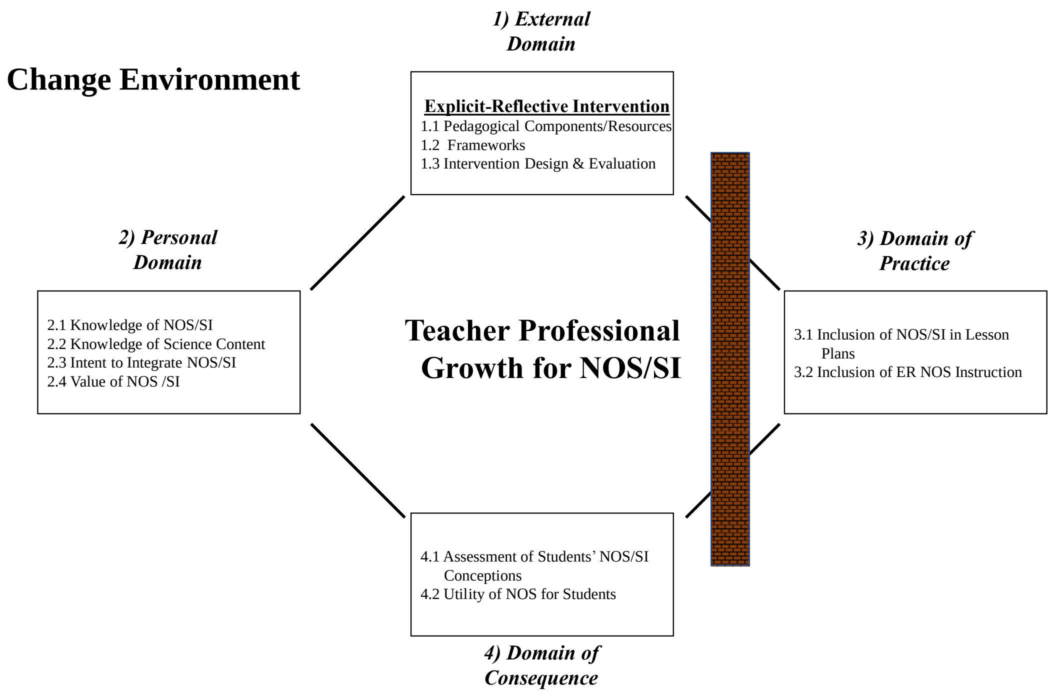

Figure 2.7. Barrier to achieving teacher professional growth for NOS and SI.

Domain of Consequence

One factor likely to mediate the translation of teachers' NOS knowledge into classroom practice is whether teachers assess and monitor their students' NOS conceptions (Wahbeh & Abd-El-Khalick, 2014). Few ER NOS interventions included factors in the domain of consequence making this domain an area for future exploration.

Change Environment

The IMTPG was used as an analytical framework to examine factors that resided *within* teachers' change domains. However, whether teacher professional growth occurs is also highly dependent on factors that reside *outside* these domains in the teachers' change environment (Opfer & Pedder, 2011). The foci of the studies included in this review were on the ER NOS intervention within methods courses, summer professional development settings, etc. Rarely was the teachers' larger change environment (e.g., school community, administration, cultural norms, etc.) where they would use the information gleaned during the intervention explicitly addressed by the authors. I did not examine each study to identify factors within the IMTPG change environment that may have hindered or facilitated the transfer development of NOS PCK. However, I recognize the importance of change environment factors, such how NOS and SI are included in standards documents (Nouri & McComas, 2016) and the portrayal of NOS in textbooks (Abd-El-Khalick, Waters, & Le, 2008). Abd-El-Khalick and Lederman (2000) found teachers' perceived pressure to cover content and institutional constraints mediated whether teachers included NOS instruction. These factors, among others, may influence teachers' ability to transfer NOS knowledge into classroom practice and should be explicitly addressed in future ER NOS interventions.

Future Research

My recommendations for future research do not differ much from those made by Abd-El-Khalick and Lederman (2000) in their seminal review of the literature almost two decades ago. They called for research to identify and isolate factors thought to be important to teacher professional growth for NOS and then determine the role these factors play in how teachers transfer NOS knowledge into practice. While researchers have identified and described these factors, the current review demonstrates that these factors have not been sufficiently isolated to determine the role they play in developing K-12 teachers' NOS PCK. The next step in NOS and SI research requires a shift in our thinking about how we approach study designs that test ER NOS interventions. This shift requires consideration of the following methodological considerations revealed by this review:

1) Design Features

Breaking down the barrier preventing teachers from including ER NOS and SI instruction in K-12 classrooms (Figure 2.7) will require approaching NOS and SI research with teachers from different methodological perspectives than what has previously been used. Using the knowledge gained over the past two decades, researchers have the information to incorporate more robust experimental designs in future studies. This will refine our understanding of what factors account for the changes in teacher professional growth. The current literature review revealed that research on improving teachers' NOS understandings and practices rarely included experimental design features such as comparison or control groups, large sample sizes, or effect sizes that would allow us to untangle causal factors that may explain changes in teacher professional growth.

Future studies that examine teacher professional growth for NOS or SI include at least two of the three following design features: comparison or control groups, a measure of whether developed NOS views were retained over time, and effect size metrics. The rational for including these in future work will be briefly described below.

2) Comparison or Control Groups

When evaluating outcomes of teacher professional development, it is extremely difficult to "disentangle the relative impacts of the factors that mediate the translation of teachers' NOS understandings into their practice, as well as the interrelationship between these factors" (Wahbeh & Abd-El-Khalick, 2014, p. 428). Including comparison groups, no matter how small, will enable NOS researchers to begin to untangle mediating factors to better understand what combination of approaches used in ER NOS instruction are most effective, for whom, and under what conditions in a more generalizable fashion.

3) Retention of NOS/SI Views

As Mulvey and Bell (2016) argue, if teachers are expected to translate NOS into their classroom practices, they must retain improved NOS views over time. Few studies examined the long-term retention of teachers' NOS conceptions, and of the studies that did include delayed post assessments, there were mixed results. Therefore, including a delayed measure would strengthen claims of effectiveness for ER NOS interventions and their potential to help teachers translate knowledge into practice.

4) Reporting Effect Size

Reporting of effect sizes in education research is recommended to provide information about the practical significance of an intervention (American Psychological Association,2012; Lipsey, 2012; IES, 2016). Abd-El-Khalick and Lederman (2000) reviewed the literature regarding teacher professional growth for NOS and criticized earlier studies for failing to report sufficient information to calculate effect sizes. Despite this, researchers have not heeded this advice as evidenced by the few studies that have reported effect sizes in the past two decades since that review. While the nature of data collected using the VNOS, VOSI, and VASI instruments is intentionally qualitative (see Lederman, 2006), categorical data can be analyzed to determine shifts in growth (positive or negative) and hence, provide effect size estimates (Wilcoxon, 1945) needed for understanding practical significance. A benefit in reporting standardized effect size is that the magnitude of the effect can be compared across interventions that target the same constructs (Lipsey, 2012). Reporting effect sizes for ER NOS interventions would provide a standardized metric that would enable researchers to compare the practical significance of their approach in relation to other similar interventions.

5) Design Experiments

Lastly, I suggest the use of design experiments in future research. Design experiments (Cobb, diSessa, Leher, & Schauble, 2003) are often used in education research because they can allow education researchers to “develop theories [and] empirically tune what works” (p. 9). Theory development may help us better explain how certain factors “impede or facilitate” the transfer of teacher knowledge of NOS into practice.

Conclusion

Over the past two decades, numerous studies have examined factors thought to facilitate K-12 teacher professional growth for NOS and SI, such as NOS conceptions, knowledge of science content, intentions to integrate NOS, and planning lessons to explicitly include NOS. While this research has yielded a tremendous amount of information about factors that may mediate teacher professional growth, these factors have not been sufficiently isolated to determine the role they play in developing K-12 teachers' NOS PCK.

The goal of intervention research in education is for educators to be able to transfer what is learned in a research setting into typical, average classrooms (Brown, 1992). In order to remove the barrier that is preventing teachers from translating knowledge of NOS gained in professional development into their classroom practice, research should 1) continue to focus on assisting teachers in developing deep, connected knowledge about NOS and SI, and 2) consider methodological approaches that will enable science teacher educators to isolate factors known to impede or facilitate teacher professional growth for NOS and SI. This will enable researchers to continue to build on previous research and extend our knowledge about how to best promote teacher professional growth for NOS and SI.

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APPENDICES

APPENDIX 2.A

IMTPG Domain Variables

Frequency of IMTPG Domain Variables in ER NOS Studies 2000-2017

Domain Variable	**Coding Description**	**N = Studies (%)**
Personal		
Knowledge of NOS/SI	The ER NOS/SI intervention explicitly targeted NOS or SI conceptions as defined by current science reform recommendations (e.g., NRC, NGSS).	39(100)
Knowledge of Science Content	The ER NOS/SI intervention included a focus on science content (e.g., physics, biology, earth science) in addition to NOS/SI.	19(48)
Intentions to Integrate	The ER NOS/SI intervention targeted changing teachers' intentions to include NOS/SI in classroom practice, or included a measure of intentions to integrate NOS, or explicitly described intentions as an outcome variable necessary for teachers to translate NOS knowledge into practice.	7(18)
Value/Utility of NOS	Teachers' value of NOS/SI instruction or beliefs about the utility of developing their own or students' NOS/SI conceptions included as a salient feature to changing NOS teaching practices.	3(8)
Practice		
Inclusion of NOS in Learning Objectives	The ER NOS/SI intervention included having teachers plan for explicitly including NOS/SI learning objectives by developing lesson plans or activities to target students' NOS/SI conceptions.	21(54)
ER NOS Instruction	NOS/SI conceptions developed in the ER NOS/SI intervention were translated into teaching practice.	14(36)
Consequence		
Students' NOS Conceptions Assessed	The ER NOS/SI intervention included having teachers assess student conceptions through written or oral responses.	10(26)
Utility of NOS for Students Considered	The ER NOS/SI intervention included investigating teachers' rationales for including NOS in classroom instruction.	1(3)

CHAPTER THREE: USING EXPLICIT AND REFLECTIVE STRATEGIES IN A BIOLOGY COURSE TO DEVELOP PRE-SERVICE ELEMENTARY TEACHERS' UNDERSTANDINGS OF NATURE OF SCIENCE AND SCIENTIFIC INQUIRY

Introduction

Developing teachers' epistemological understandings of nature of science (NOS) and scientific inquiry (SI) has been and continues to be a major goal of K-12 science education reform (AAAS, 1990, 1993; Lead States, 2013; NRC, 1996, 2000, 2011). In this context, NOS is defined as a way of knowing, which includes the "values and assumptions inherent to the development of scientific knowledge" (Lederman, 1992, p. 331). Related, though distinct, SI is the process used to generate scientific knowledge (Lederman & Flick, 2006; Lederman, 2007). There is agreement within the K-12 science education community that having sophisticated NOS and SI understandings is vital to the development of a scientifically literate citizenry (Bybee, 1997; Driver, Leach, Millar, & Scott, 1996). Indeed, "…without a proper understanding of NOS one cannot truly understand the process of science, make well-informed decisions about socio-scientific issues, or fully appreciate the importance science has in our contemporary culture" (McCain, 2016, p. 4).

There are aspects of NOS and SI that are relevant and accessible to K-12 learners and are at a level of generality that can be agreed upon by science teacher educators (Lederman, 2007; Smith, Lederman, McComas, & Clough, 1997). While there is no single list of NOS and SI aspects, those that framed the current study are listed in table 3.1. These aspects are uncontroversial with "clear implications for school science teaching" (Clough, 2006, p. 463) and have been included in K-12 science standards documents for decades (NRC, 1996; 2012). The current study was exploratory in nature, and as such, a subset of the NOS and SI aspects listed below were emphasized more than others (see aspects with asterisks in Table 3.1). Providing opportunities for future science teachers to develop sophisticated conceptions of NOS and SI, beginning with even a few aspects, is the first step in meeting the goals set forth in K-12 reform documents.

Table 3.1

Common Aspects of Nature of Science and Scientific Inquiry

Scientific Knowledge	**Process of Generating Scientific Knowledge**
<u>*NOS*</u>	<u>*SI*</u>
• Empirically based*	• Investigations begin with and are guided by scientific questions*
• Tentative, yet durable*	• No single set or sequence of steps in a scientific investigation (no one scientific method)*
• Subjective and theory-laden	• Data are not the same as evidence*
• Product of human imagination and creativity	• Scientific explanations are developed using evidence and what is already known
• Theories & laws are distinct types of knowledge	• Conclusions must be consistent with data
• Society and culture affect scientific knowledge	• Scientists work in a community of practice
• Difference between observations and inferences**	• Scientists following the same procedures will not necessarily arrive at the same results

Note. *Aspects were the major focus of the current study. **Aspects were sometimes referred to as "human endeavor" as this is the language used in NGSS

National and state standards for education are central to preservice teacher preparation (Delandshere & Arens, 2001). As such, the Next Generation Science Standards (NGSS) have been the most recent impetus for national and state science reform in K-12 education and teacher preparation since their release in 2013 (Bybee, 2014). Prior to NGSS, NOS had been recognized as an important component in science education reform documents (AAAS, 1993; NRC, 1996) and position statements of professional science teacher organizations, such as the National Science Teacher Association (NSTA). However, while NOS is included in the NGSS document, it is not centrally featured, having been relegated to an ancillary appendix (See Appendix H, Lead States, 2013). In addition, the inclusion of NOS alongside crosscutting concepts within the main section of the NGSS document was inadequate (McComas & Nouri, 2016), making it difficult for teachers to utilize NGSS to incorporate NOS into their classroom instruction. Not having NOS prominently or adequately featured in the most recent iteration of science standards documents for K-12 educators may hinder future teachers from incorporating NOS in their classroom practice (Akerson & Donnelly, 2008).

Much instructional time with preservice elementary teachers (PSET) in science courses is dedicated to the vast amount of science content teachers are expected to know and teach, leaving little time for science teacher educators to include NOS and SI, let alone model a reflective orientation for teaching and learning. This poses a major challenge for teacher educators who wish to explicitly include aspects of NOS or SI and provide time for PSET to reflect and develop epistemological science understandings. This problem was the impetus for the current study which aimed to develop and compare the effectiveness of two explicit and reflective (ER) NOS/SI interventions that could easily be assimilated into preservice teacher science courses, regardless of the existing curricula. Both interventions used in this study were designed to assist PSET in refining their understandings about the nature of scientific knowledge and develop more expert-like conceptions of NOS and SI, congruent with the recommendations explicated in standards documents. The following section outlines the conceptual and analytical framework used in this study to examine PSET professional growth.

A Framework for Teacher Professional Growth for NOS and SI

Despite receiving less attention in NGSS, NOS and SI have continued to be a focus of research and professional development for preservice elementary teachers (Lederman & Lederman, 2014). This research shows that overall, PSET hold conceptions of NOS and SI that are incongruent with science reform recommendations (Abd-El-Khalick & Lederman, 2000; Lederman, 1992; Schwartz, 2008). In addition, even when conceptions are adequately developed, PSET struggle to include aspects of NOS in their teaching practicum (Akerson, Pongsanon, Park Rogers, Carter, & Galindo, 2017; Akerson, Morrison, & McDuffie, 2006; Kucuk, 2008).

Considering this gap, there is a need to continue to examine how PSET can grow professionally to better understand NOS and SI, as well as develop pedagogical approaches to include these constructs in their future science instruction. Numerous empirically-based models have been developed to guide professional development for teachers (e.g. Guskey, 1986) but a major criticism has been that these models are over-simplified and cannot sufficiently explain the complex processes involved in teachers' professional growth (Avalos, 2011; Clark & Hollingsworth, 2002; van Driel, 2014). Indeed, developing teachers' NOS and SI conceptions is a complex endeavor (Abd- El-Khalick, 2000; Lederman and Lederman, 2014). As such, for the current study the Interconnected Model of Teacher Professional Growth (IMPTG) (Clarke & Hollingsworth, 2002) was used as both a conceptual and an analytical framework because this model assumes teachers' change is complex and non-linear (Figure 3.1).

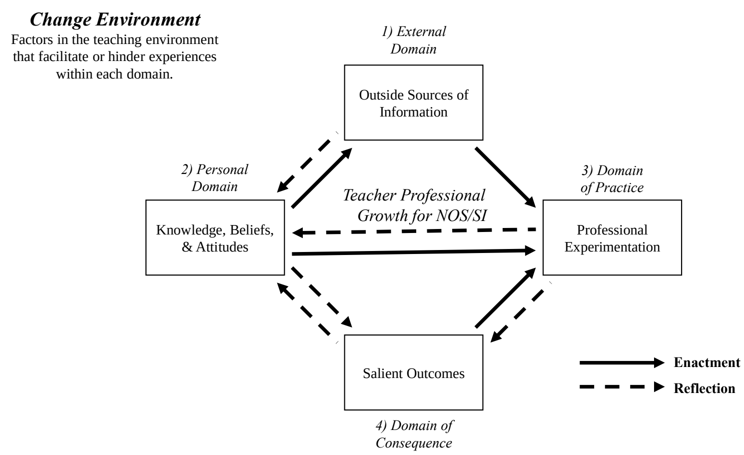

Figure 3.1. The Interconnected Model of Teacher Professional Growth (IMTPG). Adapted from "Elaborating a Model of Teacher Professional Growth," by D. Clarke and H. Hollingsworth, 2002, *Teaching and Teacher Education, 18*, p. 951.

Domains in the IMTPG (indicated in the boxes in Figure 3.1) are four broad categories comprised of various factors that are thought to influence teacher professional growth. The categories enable explanation of the complex interactions that occur between and within the domains that influence teacher professional growth. The external domain (1) includes any external stimulus from outside the boundaries of the teaching environment but influences events that occur inside the classroom. Oftentimes, the external domain consists of a professional development experience or intervention. The personal domain (2) includes any characteristic of the instructor that they bring with them into their practice, such as personal beliefs, attitudes, and/or content knowledge. The domain of practice (3) includes the pedagogical decisions and approaches used by the teacher in their classroom. The domain of consequence (4) consists of the salient student outcomes desired by the teacher, such as student understanding or behavior.

Within the IMTPG, all of the domains are situated within the teacher's change environment. Reflection plays a central role in the process, as factors in one domain influence factors in other domains. Reflection is defined per Dewey (1910, p. 6) as "active, persistent and careful consideration," and this process is identified as a mechanism responsible for spurring changes among domains. Clarke and Hollingsworth (2002) have reported that there has been "considerable success" (p. 957) using the IMTPG to categorize teacher change data into each of the four domains and identify the processes by which the changes occurred.

The current study aimed to examine a specific area of professional growth for PSET within the IMTPG, the personal domain. A review of the literature (Chapter 2 of this dissertation) revealed that two important factors necessary for teacher professional growth for NOS and SI fall into this domain. These are 1) sufficient knowledge of NOS and SI, and 2) teachers' intentions to integrate NOS and SI. With these two critical factors in mind, as well as the key role reflection plays in teacher professional growth, the current study examined whether two professional development-type interventions focused on NOS and SI differed in regards to quantity and quality of PSET reflection, and hence, changes in the personal domain (Figure 3.2). The next section only briefly reviews this literature. For a comprehensive review of this literature see Chapter 2.

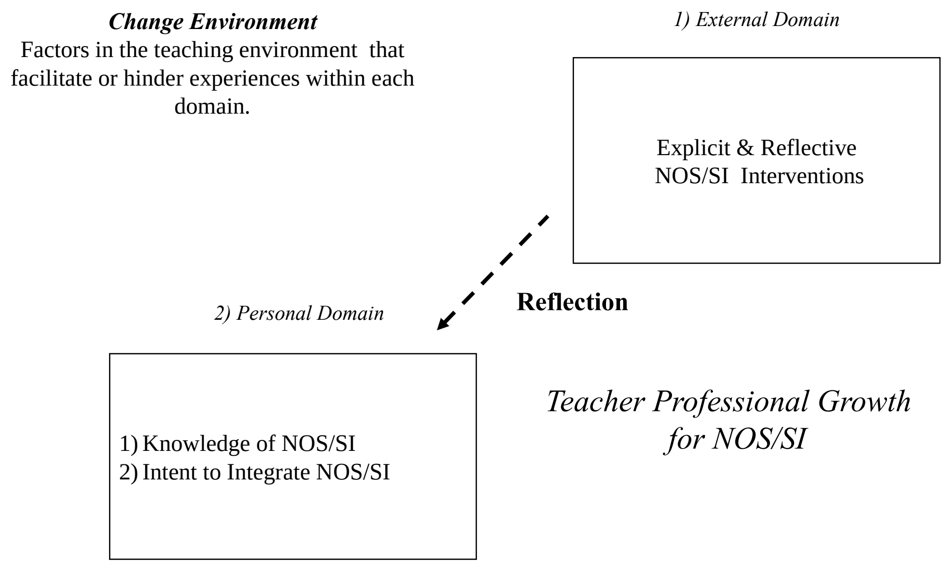

Figure 3.2. The examination of changes in the IMPTG personal domain and the mechanism of reflection due to an ER NOS/SI intervention (external domain).

Personal Domain Factors

Changing NOS & SI Conceptions

Although a variety of approaches have been used to improve teachers' conceptions of NOS (e.g., McComas, 1998), a large body of evidence supports that using explicit and reflective (ER) strategies in the context of teacher preparation courses is an effective means to improve PSET NOS conceptions (Abd-El-Khalick & Lederman, 2000; Abd-El-Khalick & Akerson, 2009; Ozgelen, Hanuscin, & Yilmaz-Turin, 2012, among others). In general, ER strategies use instructor questioning or group discussions to make targeted aspects of NOS and SI visible in the classroom (Lederman & Lederman, 2004). In addition, time is provided for teacher-learners to reflect on their understandings by journaling or engaging in other metacognitive activities (e.g., concept mapping) individually or with others (Abd-El-Khalick & Akerson, 2009). Decades of research have shown that unless teachers engage in professional development that explicitly addresses NOS conceptions and provides teacher-learners with opportunities to reflect on their views of NOS, they are not likely to develop views aligned with science reform recommendations (Abd-El-Khalick & Lederman, 2000; Akerson & Hanuscin, 2007; Burton, 2013; Morrison, Raab, & Ingram, 2009).

Changing Intentions to Implement NOS and SI Instruction

A second factor within the IMPTG personal domain that cannot be overlooked is teacher intent to integrate NOS and SI in their classroom instruction. Developing PSET NOS and SI conceptions through reflection is necessary (but not sufficient) if the goal is for future teachers to include NOS in their classroom practice (Lederman, 1999; Lederman & Lederman, 2014). Research suggests that after developing sophisticated NOS conceptions, the next most important factor for teachers is to have intentions to integrate NOS in their science instruction because this factor likely mediates the translation of NOS knowledge to teaching practices (Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001; Lin, Lieu, Chen, Huang, & Chang, 2012; Mulvey & Bell, 2016; Demirdogen & Uzuntiryaki-Kondakci, 2016). Therefore, teachers' intentions regarding NOS need to be considered when science teacher educators model NOS pedagogy or make attempts to change teacher personal domain factors, such as beliefs and values regarding the teaching and learning science (Abell & Bryan, 1997).

ER NOS Interventions

The following sections will describe the rationale for each ER NOS intervention as well as how these were used within a biology course for PSET. I begin by providing a description of the rationale and structure for each intervention based on an ER approach supported by the literature. This is followed by a brief description of how each intervention was used as a means to promote professional growth in the teacher sample in this study.

Intervention 1: NOS for Science Education (NOSSE) Guide ER Strategy

The first ER NOS intervention, the *NOSSE Guide ER Strategy*, was created for this dissertation because NOS and SI may be hidden in current standards documents. To make NOS aspects explicit, I reviewed K-12 standards documents, position statements on NOS, and relevant research literature in teacher education to compile and create one-page NOS for Science Education (NOSSE) Guides (see Figure 3.3). Each guide explained a particular NOS or SI aspect in a manner congruent with K-12 science reform recommendations. In the current study, NOSSE Guides were created for the a) empirical nature of scientific knowledge, b) science as a human endeavor (the distinction between observation and inference), c) the difference between data and evidence, and d) there is no single, step-wise scientific method.

Science Education Standards Documents: Empirical Nature of Scientific Knowledge Part 1

Next Generation Science Standards (p. 5, Appendix H)

Aspect of Scientific Knowledge	*K-2 Understandings*	*3-5 Understandings*	*Middle School Understandings*	*High School Understandings*
Scientific Knowledge is Based on Empirical Evidence	Scientists look for patterns and order when making observations about the world.	Science findings are based on recognizing patterns. Scientists use tools and technologies to make accurate measurements and observations.	Science knowledge is based upon logical and conceptual connections between evidence and explanations. Science disciplines share common rules of obtaining and evaluating empirical evidence.	Science knowledge is based on empirical evidence. Science disciplines share common rules of evidence used to evaluate explanations about natural systems. Science includes the process of coordinating patterns of evidence with current theory. Science arguments are strengthened by multiple lines of evidence supporting a single explanation.

Figure 3.3. Example of part of a NOSSE Guide. All guides can be found in Appendix 3.C.

NOSSE Guides were constructed to provide an explicit description of NOS and SI representative of an “expert-like” view for each aspect and were tailored to the specific learning objectives of the biology course where the study took place. For example, the NOSSE Guides constructed for the current study were based on information in the state and national science standards because the course objectives were aligned with the biology content found in the standards documents.

Not all suggested NOS aspects are adequately described in national and state science standards documents. Therefore, to fill in gaps that arose while constructing

NOSSE Guides for NOS and SI aspects not included in standards documents, the NSTA position statement on NOS (2000), excerpts from *Teaching About Evolution and Nature of Science* (National Academy Press, 1998), and other resources written for the teaching and learning of NOS in K-12 settings (e.g., *Keys to Teaching the Nature of Science*, NSTA Press) were used.

The reflective component of the NOSSE Guide ER Strategy consisted of having participants determine how specific course activities (e.g., modeling population growth, collecting and interpreting data, etc…) aligned with the NOSSE Guides. Course activities were provided on cards and participants had to select activities and justify how each aligned with the NOS or SI aspect presented in the NOSSE Guide.

Intervention 2: NOS Example Strategy

The second ER NOS intervention used the NOSSE Guides developed for the NOSSE Guide ER strategy, but incorporated ostensive examples for the purpose of potentially inducing cognitive conflict (Kang, Scharmann, & Noh, 2004; Piaget, 1963), thereby spurring more teacher reflection. Ostention is a process that has been used successfully to help learners across content domains develop mental representations of concepts by using rules, prototypes, or exemplars (Kuhn, 1974) and is not a new approach for teaching and learning (Bruner, Goodnow, & Austin, 1956; Schwartz & Bransford, 1998). In fact, ostention has been used to successfully develop teachers' conceptions of NOS (Bilican, Cariroglu, & Oztekin, 2015; Bloom, Binns, & Koehler, 2015; Craven, Hand, & Prain, 2002; Demirdogen & Uzuntiryaki-Kondakci, 2016; Smith & Scharmann). Examples, both exemplars and non-exemplars, were the foundation of the second ER NOS intervention, hence the strategy is referred to as the *NOS Example Strategy*.

The NOSSE Guides served to make NOS aspects explicit in both interventions, but the reflective component of the NOS Example Strategy consisted of a pool of short answer responses that represented student or teacher thinking about specific aspects of NOS and SI. Responses were culled from the most widely used survey instruments to measure NOS and SI understandings, the Views of Nature of Science (VNOS) questionnaire (Lederman et al., 2002), the Views of Scientific Inquiry (VOSI) questionnaire (Schwartz, Lederman, & Lederman, 2008), and the Views About Scientific Inquiry (VASI) questionnaire (Lederman et al., 2014). These questionnaires require respondents to provide short answers to questions that target NOS or SI aspects. For example, one question from the VNOS (version D) asks, "After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change?" This question aims to elicit respondents' views regarding the tentative, yet durable nature of scientific knowledge, and potentially the distinction between theories and laws. Exemplar responses were purposely selected to be representative of adequate, mixed, and inadequate NOS views (Table 3.2) to provide model cases representative of how novices and experts (Ericsson & Smith, 1991) would conceptualize NOS and SI aspects.

Table 3.2

Types of Exemplar Responses Culled from the Literature

	Exemplar Responses from the VNOS Question: *"After scientists have developed a scientific theory (e.g., atomic theory, evolution theory) does the theory ever change?"*	
NOS Aspect	More Naïve NOS View	More Adequate NOS View
Scientific knowledge is tentative, durable, and self-correcting	I believe scientific theories do not change. Theories are products of long term studies. In order for a hypothesis to become a theory, it should be proven over and over again for so long and should give the same results every time[1].	Scientific laws like theories change because we do not know all the answers in science. Something we believe to be true now may be found out later is wrong or different. Once upon a time it was believed the earth was flat but then with more information, we learned it is actually round. Science is always changing and science is tentative[2].
	A great example of theory change is the always-baffling unanswered question of how to lose weight. At least hundreds, if not thousands of theories exist on this topic, many of which contradict one another and confuse the public[3].	Yes, scientific knowledge may change. In my opinion science is a living study. By that I mean it may change as our ability to observe and investigate improves over time. In addition, our way of thinking and interpreting data is developing and changing. There are many examples of changing scientific knowledge. Examples of changing scientific knowledge are as old as the Earth centered universe and the flat Earth theory. Also, recently, Einstein's theory overturned Newton's theories[4].

Note. Exemplar responses by students or teachers *directly* from [1] Pelin, 2012, p. 127, [2]Mesci & Schwartz, 2017, p. 11, [3] Matkins et al., 2002, p. 8, & [4] Project ICAN (Inquiry, Context, & Nature of Science) Report.

While developing mental representations of concepts by contrasting model cases (i.e., conceptual analysis and ostention) is not a new approach to learning (Bruner, Goodnow, & Austin, 1956; Rosch, 1975; Schwartz & Bransford, 1998), using responses from NOS questionnaires as reflective tools to develop NOS conceptions has not been examined in the literature to the best of my knowledge. Exemplars from the VNOS, VOSI, and VASI were carefully selected to represent the contrast between novice and expert views of NOS. Careful selection of exemplars is important when defining conceptual boundaries, as described by Kahn and Zeidler (2016) in a recent article on conceptual analysis. The authors use Kuhn's example of a young child trying to develop the concept of a bird:

> Clearly, if a person who had never seen a bird asked, 'Can you show me a bird?' you would be reluctant to use penguins or emus as examples as they are not model cases of birds in the way sparrows or finches are. By focusing on the conditions that make these borderline cases different from model cases, we can more specifically refine our concept of what is and is not necessary for a complete concept of a bird (p. 543).

Aspects of a design experiment methodology (Cobb, Confrey, diSessa, Leher, & Schauble, 2003) were used to make improvements to NOSSE Guides and delivery of the intervention by examining data after each implementation of the strategies and making changes prior to the next iteration. For example, Peer Instruction (Mazur, 1997), a strategy in which participants justify their responses, was used in place of the exemplar card placements in the final iteration of both the NOSSE Guide ER Strategy and the NOS

Example Strategy in an attempt to promote richer, more guided small-group discussion between the preservice teachers in this sample.

Implementation and Use of Interventions

Both the NOSSE Guide ER Strategy and NOS Example Strategy required PSET to work in small groups (3 to 4) to examine a NOSSE Guide, and in their own words, describe the view of NOS and SI presented therein. In this way, NOSSE Guides were used to make NOS and SI aspects explicit and visible to teacher-learners. The NOSSE Guides were laminated so participants could underline and mark on them as they prepared a summary to explain the view of science presented in the guide. Once the participants demonstrated understanding of the aspect of NOS or SI in the NOSSE Guide, each intervention group reflected on NOS and SI differently. In the NOSSE Guide ER Strategy group, participants reflected on course activities and content experienced during the biology course in which the study took place. In the NOS Example Strategy group, participants reflected on ostensive examples (Figure 3.4).

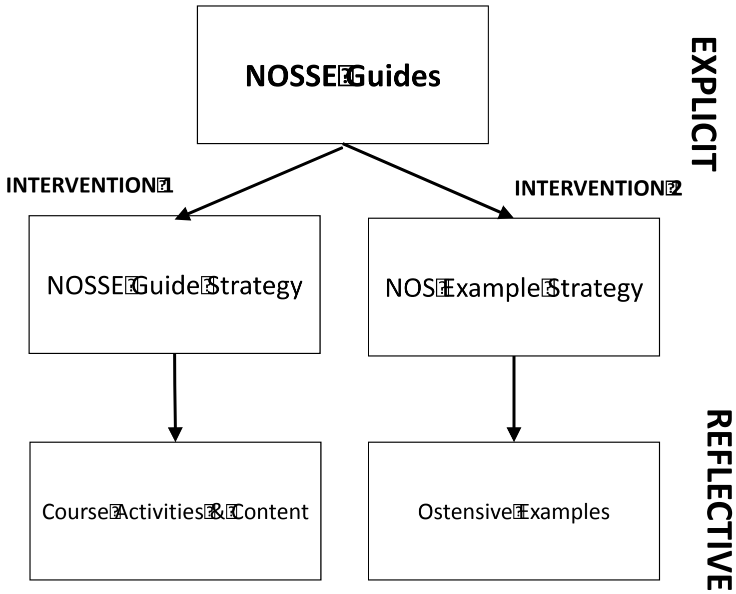

Figure 3.4. Diagrammatic representation showing the comparison of study interventions aligned with an ER approach.

Reflection in both intervention groups required participants to examine provided cards and place them according to information from the NOSSE Guides. In the NOSSE Guide ER Strategy group, study participants were given twenty activity cards, each with a specific activity completed thus far in the biology course. In small groups of 3-4, the PSET were asked to choose five activity cards and place them on the NOSSE Guide where the activity related to the NOS or SI aspect. They were required to justify their placement verbally and in writing. In the NOS Example Strategy group, study participants were given five exemplar response cards and a continuum (Figure 3.5). In small groups of 3-4, the preservice teachers were asked to place each exemplar card along the continuum based on how the exemplar response aligned with the NOSSE Guide. If an exemplar response represented a view of NOS or SI more, less, or somewhat like the expert view presented in the NOSSE Guide, participants placed the response card accordingly. They were required to justify their placement verbally and in writing.

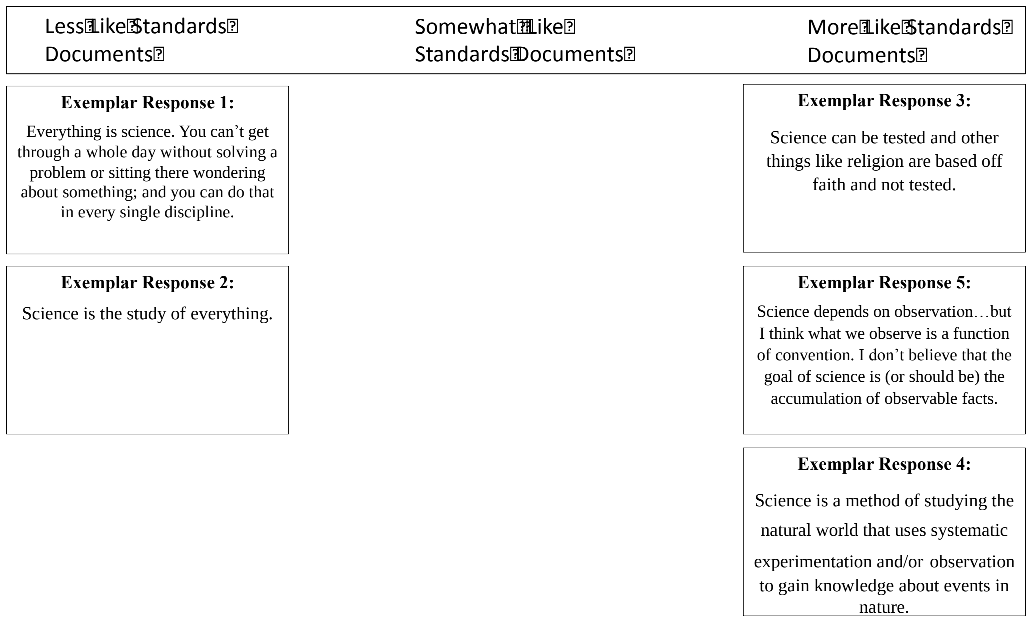

Figure 3.5. An example of how PSET placed exemplar response cards along a continuum for the empirical nature of scientific knowledge.

Purpose & Research Questions

This study aimed to assess the influence of two ER NOS interventions, the NOSSE Guide ER Strategy and the NOS Example Strategy, on preservice teachers' personal domain variables regarding NOS and SI. Both interventions used components of general ER NOS strategies found to be effective at improving teachers' conceptions of NOS and SI, such as metacognitive activities and asking teachers to reflect on NOS and SI as explicated in science standards documents. However, the NOS Example Strategy included the use of ostention where exemplars were used to promote preservice elementary teacher reflection, while participants in the NOSSE Guide ER Strategy group reflected solely on class activities. The following research questions and hypotheses guided the study:

Research Question 1) What is the influence of the NOSSE Guide ER Strategy and NOS Example Strategy on PSET reflection?

Hypothesis 1) The NOS Example Strategy induces cognitive conflict and promotes more reflective discourse than the NOSSE Guide ER Strategy that does not use examples.

Research Question 2) What is the influence of the NOSSE Guide ER Strategy and NOS Example Strategy on PSET conceptions of NOS and SI?

Hypothesis 2) The NOS Example Strategy is more effective at developing PSET conceptions of NOS and SI than the NOSSE Guide ER Strategy that does not use examples.

Research Question 3) What is the influence of the NOSSE Guide ER Strategy and NOS Example Strategy on PSET intentions to integrate NOS in future classroom instruction?

Hypothesis 3) The NOS Example Strategy is more effective at changing PSET intentions to integrate NOS than NOSSE Guide ER Strategy that does not use examples.

Methods

The current study was exploratory in nature and used a quasi-experimental, concurrent triangulation mixed-methods research design (Warfa, 2016). The goal of this design is to “obtain different but complementary data that validate the overall results” (Warfa, 2016, p. 4). Two course sections were randomly assigned to receive either the

NOSSE Guide ER Strategy or the NOS Exemplar Strategy, in which participants within a particular class all received the same intervention. Both qualitative and quantitative data was collected to answer the research questions to determine whether there were differences between the two ER NOS interventions regarding PSET NOS and SI: 1) conceptions, 2) intentions to integrate these constructs in their future classrooms, or 3) degree of reflection. Data was collected each class meeting over 16 weeks during the 2016 fall university semester.

Participants

Participants were preservice teachers enrolled in a biology course for elementary and early-childhood education majors offered at a large university in the Southeastern United States. Twenty-four undergraduate preservice elementary teachers (23 female and 1 male) with an average age of 22.1 (*SD* = 4.07) years were enrolled in the course section which was randomly designated to receive the NOS Example Strategy. Thirteen participants (12 female and 1 male) with an average age of 23.4 years (*SD* = 6.59) were enrolled in the second course section and received the NOSSE ER Strategy using NOSSE Guides, but not exemplars.

Context of the Study

The study was conducted in two sections of a 4-credit hour, upper-level biology course for early-childhood and elementary education majors. Each section met for approximately two hour class sessions, 3 times per week. Course objectives from the syllabus included helping PSET 1) learn biology content in preparation for taking the middle grade level life science Praxis exam, 2) develop a sense of wonder and curiosity about science, and 3) understand the applicability of science to everyday life.

This biology content course was purposely selected to examine the two ER NOS interventions, though methods courses are usually where PSET receive explicit NOS instruction (McComas, Clough & Almazroa, 1998). The rationale for choosing a science content course was because the primary goal of methods courses are to instruct preservice teachers how to *teach* science content they are already familiar with. Placing an emphasis on helping PSET to develop NOS understandings while concurrently providing instruction regarding pedagogical approaches may be overwhelming for novice educators (Bell, Lederman, & Abd-El-Khalick, 2000; Abd-El-Khalick, 2001). In addition, providing a science context in which to learn NOS, such as is the case with science content courses, can be beneficial to learners developing NOS understandings (Ozgelen, Hanuscin, & Yilmaz-Tuzun, 2013; Schwartz, Lederman, & Crawford, 2004).

The course instructor (not the researcher) taught both course sections and had taught the course over 40 times during the past 22 years. In addition, this instructor used rich, inquiry-based approaches to teach biology content. PSET enrolled in both course sections received explicit instruction regarding SI and science process skills, examined state and national science standards documents throughout the semester, and engaged in student-centered activities in which they worked collaboratively in small groups to complete activities (e.g., card-sorts). These experiences were similar to what was expected during both the NOSSE Guide ER Strategy and the NOS Example Strategy, making this an ideal context to explore the effectiveness of each intervention. The researcher assisted in the biology course from the first day as a participant observer (Patton, 2015) and both ER NOS interventions were developed and taught by the researcher. Each respective intervention group engaged in ER NOS instruction a total of five times throughout the semester, totaling approximately 85 minutes (Table 3.3).

Table 3.3

Intervention & Data Collection Timeline

Week	ER NOS Intervention Activity	Description
1-2	Completed Pre-Assessments	VNOS-D; VOSI-270; Intent to Integrate NOS
3	Written Reflections*	No Single Scientific Method
8	Card Sorts	Scientific Knowledge is Empirical
10	Card Sorts	Science as a Human Endeavor (Observations/Inferences; Creativity)
12	Written Reflections*	Tentative yet Durable
14	Card Sorts using Peer Instruction	Data and Evidence Differ
16	Completed Post-Assessments	VNOS-D; VOSI-270; Intent to Integrate NOS

*Note. Participants were given writing prompts unique to each intervention (*NOSSE Guide ER Strategy* and *NOS Example Strategy*) outside of class instead of engaging in card activities or Peer Instruction these weeks. Small group discourse was only recorded for interventions completed during classroom instruction.

Data Collection and Analysis

Reflection

In order to answer research question 1, PSET discourse was analyzed qualitatively to identify instances and types of reflection. Reflection has been identified as a key process needed to facilitate changes in teaching and learning at all levels (Clarke & Hollingsworth, 2002; Schon, 1983; Henderson, Beach, & Finklestein, 2011; Ward & McCotter, 2004) so it is not surprising that using ER approaches has been effective to improve PSET's NOS conceptions. However, because of the complex nature of reflection and no consensus on an operationalized definition (Hatton & Smith, 1995), teacher reflection has been difficult to quantify and measure (Akbari, Behzadpoor, & Dadvand, 2010; Rodgers, 2002; Ward & McCotter, 2004). Reflective thinking includes elements that may be identifiable, such as perplexity, hesitation, doubt, and searching for further facts (Dewey, 1910). Ward and McCotter (2004) have developed a reflection rubric to measure PSET reflection situated in classroom practice. As such, the extent to which a teacher actively reflects in other settings (e.g., professional development courses) may be measurable by coding for these elements in qualitative data (Akbari et al., 2010).

It was hypothesized that if a particular ER NOS intervention promoted more reflection, the strategy would be more effective at changing teachers' conceptions and intentions for NOS and SI. Therefore, to examine the extent to which PSET reflected while engaged in each ER NOS intervention, a coding scheme was developed and used during the content analysis of transcribed small-group discourse (Patton, 2015). This coding scheme (Table 3.4) was derived primarily from the elements of reflection identified by Akbari, Behzadpoor, & Dadvand (2010), Schon (1983), and Dewey (1910), but also from Rodgers' (2002, p. 845) extension of Dewey's work that identified four criteria of reflection: 1) reflection is a meaning-making process that promotes deeper understanding, 2) reflection is a systematic and rigorous way of thinking, 3) reflection must occur with others, and 4) reflection requires the reflector to value personal and intellectual growth. Examples are provided to clarify the qualitative differences among instances of discourse that occurred.

Table 3.4

Reflection Codes and Descriptions Used to Code Small-Group Discourse

Code	Description
Perplexity	Participant expresses uncertainty about existing knowledge of a NOS or SI aspect from NOSSE Guide or others' ideas. *Example:* "Everything? Hmm. 'Science can be tested, and other things like religion are based off faith and not tested'…"
Hesitation	Participant pauses and reconsiders a statement about a NOS or SI aspect, either from NOSSE Guide or another student. *Example:* "Which is an inference, but like at the same time it's not really [pause]…I wouldn't [pause]… I would say it's more like trial and error as opposed to like scientific, like, theory.
Doubt	Participant expresses uncertainty about an idea related to a NOS or SI aspect from the NOSSE Guide. *Example:* "To me, I mean, I don't see how, I mean I guess it depends on what - what your data is and what you're looking at. I feel like data is data. Like either you saw something or you didn't. You know? Like when you're recording data? I don't know."
Searching for Facts	Participant searches or is directed to search for facts about NOS or SI from the NOSSE guide, from others, or from their prior experiences. *Example*: "I'll try, try to find one that says something about inferences and then we can use that standard as example."
Deliberation	Participant evaluates different or alternative ideas about NOS and SI aspects, then integrates new knowledge about NOS and SI with what is already known to make a decision; Carefully analyzes information to come to a conclusion about a NOS or SI conception. *Example:* "Yeah, they're comparing with the knowledge that they have. But it's not that they're just trying to match it. So teacher 5 said 'science is something that is straightforward and isn't a field of study that allows for opinions, personal bias or individual views.' It is totally observation and fact based. I think that is false because of inferencing."

Table 3.4 continued

Code	Description
Meaning-Making	Participant rephrases NOS or SI idea; may provide an example from their experience or try to make sense of other people's NOS or SI viewpoints to comprehend ideas that are contrary to their current understandings or beliefs. May make comparisons to make sense of NOS or SI ideas. *Example:* "And we can say…so…human inference on data is how science works. Science is a study that belongs to humans."
Rigor of Thinking	Participant is systematic in reasoning about NOS and SI by connecting the ideas from NOSSE Guides to their thinking and experiences; provides clear explanation for conclusion about NOS or SI conception. *Example:* "Well, interpret - it [NOSSE Guide] says interpreted with theory. So we take our observations and inferences and we turn them into a theory. And so that's something that people do, so if people didn't do it, it wouldn't happen."
Reconsideration of Existing Knowledge	Participant makes a correction, or change, about a previous statement or action describing or explaining a NOS or SI aspect. *Example:* I don't think empirical can just mean "natural". Because it wouldn't make sense to be natural nature of scientific…
Affirmation	Participant agrees with another statement about NOS or SI and/or acknowledges a previously stated NOS/SI idea. *Example*: I'd say so, because you can start building around the skeletons that you already have. So you would know some shapes, you know, and structures, and what they look like.
Alternative Meanings	Participant suggests a different meaning for something regarding NOS or SI, something other than what was previously stated or as in NOSSE Guide. *Example*: "It [empirical] means fact-based"

Note. Examples were taken directly from small-group discourse coded for this study.

PSET in both course sections worked in small groups of 2 to 4 participants as they engaged in their respective interventions, a total of five times during the semester (Table 3.3). The intervention took place two additional times during the semester, but in these instances participants engaged in the two interventions as take-home assignments completed individually and outside of class time. This is a study limitation and was due to practical time constraints in the course. Take home assignments were not coded for reflection because of Roger's (2002) condition that reflection occurs between others, but were used to make adjustments to the next iteration of intervention implementation (Cobb et al., 2003). For the interventions that occurred during class time, at least two small groups were randomly selected to have group discourse recorded using a Livescribe ® pen and notebook. Individuals self-selected into their small groups, though the course instructor required participants to switch groups weekly. All recordings were transcribed and instances of reflection for each group were identified using the *a priori* coding scheme (Table 3.4).

Transcriptions of small group discourse that occurred during the implementation of each intervention were blinded for intervention condition before being coded by the researcher to reduce interpretation bias. An equal number of small groups were recorded for each condition, but due to poor audio quality, two small groups in the NOS Example Strategy condition were not included in the data. Time on task was approximately the same across conditions for each implementation of the intervention (Table 3.3). For example, participants in the NOSSE Guide ER Strategy group spent a total of fifteen minutes engaged in the intervention that focused on the empirical nature of scientific knowledge, so the NOS Example Strategy group spent a similar amount of time on that aspect (within a few minutes). However, the total amount of time did vary across each implementation, so instances of reflection were normalized by calculating the number of reflective instances per minute to be able to make relative comparisons for reflection between intervention groups. Reflective instances per minute were averaged for each intervention group for comparative analysis.

Conceptions of NOS and SI

To answer research question 2, participants completed abridged versions of the Views of Nature of Science (VNOS) version D (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) and Views of Scientific Inquiry (VOSI) version 270 (Schwartz, Lederman, & Lederman, 2008) during the first and last week of the course (Appendix 3.B). The VNOS and VOSI consist of open-ended, short answer questions that gauged how individuals perceive and understand processes in science responsible for generating and justifying scientific knowledge (SI) and aspects regarding the nature of this knowledge (NOS). For the current study, the questionnaires were modified to target specific aspects of NOS and SI. These modifications were made based on the course syllabus and discussions with the instructor prior to the start of the semester.

Per the VNOS and VOSI protocols, follow-up interviews were conducted with approximately 15% of the participants to ensure written responses accurately represented participant views. Interviews were audio recorded and transcribed. The post test was administered during the PSET final exam, and to extract participants' perspective of NOS and SI gained from the context of the biology course, they were specifically asked to support their responses with examples from the course.

Participants' pre-and post-responses were coded as naïve, mixed, or informed for NOS and SI aspects, as typical of analysis of these instruments (Lederman et al., 2002). Responses were coded as *informed* if the PSET view was congruent with accepted definitions or conceptions of NOS and SI found in standards documents. *Naïve* responses reflected misconceptions or a lack of understanding, while a *mixed* response was partially correct or contradicted other responses. Surveys were scored independently by two raters with experience scoring the VNOS and VOSI. Initial interrater reliability was 73% for the VNOS-D and 93% for the VOSI-270, and all scoring discrepancies were resolved by further discussion and reevaluation until 100% agreement was reached for each participant.

Intention to Integrate NOS

To answer research question 3, participants completed the Intention to Integrate Nature of Science Questionnaire (Akyol, Oztekin, Sungur, & Abd-El-Khalick, 2016) to measure latent variables that may explain PSET intentions to integrate NOS into their future classroom instruction. The questionnaire consisted of 52 Likert-type items. Due to the exploratory nature of the original implementation of the instrument in the Akyol et al. (2016) study, an exploratory principal component factor analysis with varimax rotation (SPSS 21.0) was conducted using current study participants' post questionnaire scores. The initial factor analysis explained 83.4% of the cumulative variance and the rotated component matrix was used to identify reliable latent variables of interest in the context of the current study (Table 3.5). Items that did not intercorrelate with the hypothesized constructs in this particular sample were removed from the analysis.

A total of seven variables were identified based on the remaining 40 items (Appendix 3.A) and were of interest in the current study (Table 3.5 below): 1) teachers' readiness to integrate NOS into classroom instruction, 2) teachers' perception of the utility of NOS knowledge for students, 3) the pressure teachers' perceive to integrate NOS into their future instruction, 4) teachers' beliefs about factors they can control regarding NOS integration, 5) teachers' perceived important outcomes for NOS instruction, 6) teachers' beliefs about normative expectations to integrate NOS, and 7) teachers' overall attitudes about integrating NOS. These variables were examined to determine if there were any statistically significant differences for these latent variables between participants in the two intervention groups.

Table 3.5

Factor Loadings for Exploratory Factor Analysis with Varimax Rotation of Intentions to Integrate NOS Variables

	Factors						
Item*	1	2	3	4	5	6	7
1	**.93**						
2	**.97**						
3	**.96**						
4	**.62**				.41		
5		**.67**		.42			
6		**.65**		.46			
7		**.83**					
8		**.63**					
9		**.60**		.50			
10		**.73**					
11		**.86**					
12		**.79**					
13		**.82**					
14		**.66**					
15			**.87**				
16			**.91**				
17			**.70**				
18			**.62**			.46	
19				**.79**			
20				**.86**			
21				**.69**			
22				**.79**			
23					**.62**		
24					**.83**		
25					**.63**		.44
26					**.72**		
27			.42			**.60**	
28						**.84**	
29							**.82**
30							**.56**
31							**.51**
32			.47			.44	**.62**
33							**.83**
34							**.81**
35							**.43**
36							**.74**
37							**.50**
38							**.65**
39							**.60**
40				.40			**.69**

Note. Factor loadings > .40 are reported. *Items listed in full in Appendix 3.A.

Results

The goal of the current study was to engage PSET in two ER NOS interventions and determine whether PSET professional growth for NOS and SI differed for each group. It was hypothesized that the extent and type of reflection would differ between the two intervention groups, contributing to observable differences in the personal domain variables of conception and intentions to integrate NOS and SI. The following sections will address each of the three research questions asked. First reflection was assessed with mixed data sources to examine differences between the two intervention groups. Data will then be presented to describe whether changes occurred regarding PSET conceptions and intentions to integrate NOS and SI.

Reflection on NOS & SI

Research Question 1) What is the influence of the NOSSE Guide ER Strategy and NOS Example Strategy on PSET reflection?

Both the NOSSE Guide ER Strategy and the NOS Example Strategy promoted PSET reflection on their knowledge of NOS and SI aspects (Figure 3.6). The following sections will describe the extent to which each intervention (external domain) promoted PSET reflection and then compare the types of reflection exhibited by participants as they constructed knowledge of NOS and SI (personal domain).

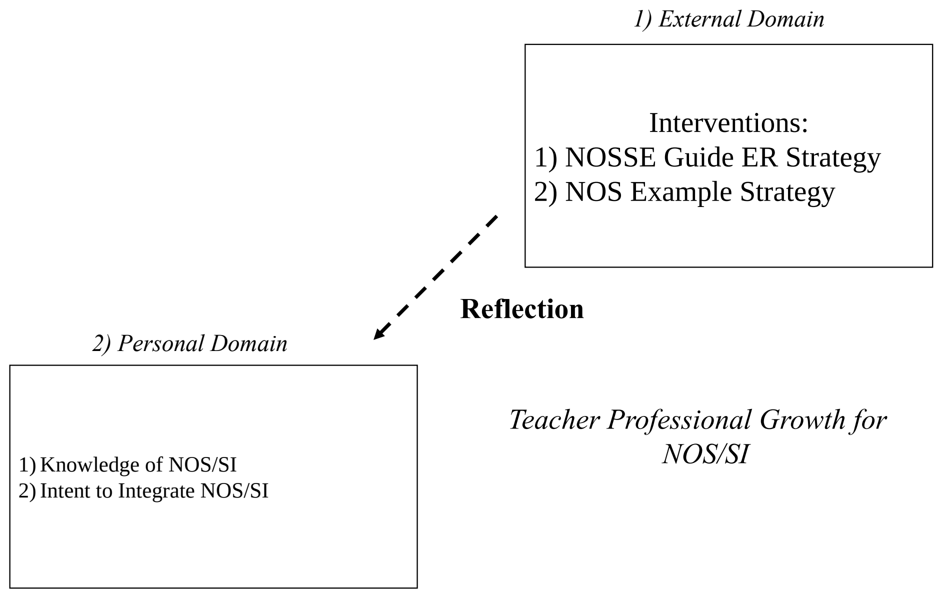

Figure 3.6. Both interventions promoted PSET reflection, a key change mechanism in the IMTPG.

Extent of PSET Reflection

The number of reflective instances observed for the two intervention groups is shown in Table 3.6. On average, participants in the NOS Example Strategy group showed more instances of reflection per minute (M = 1.44, SD = .278), than participants in the NOSSE Guide ER Strategy group (M = 1.04, SD = .476). This difference, -0.402, was not statistically significant $t(12) = -1.84$, p = .091; however, this difference did represent a large-sized effect, d = 1.07.

Table 3.6

Total and Normalized Reflective Instances per Aspect by Intervention Group

NOS/SI Aspect	Intervention	Group	Total Reflective Instances	Time (minutes)	Reflective Instances/ Minute
Empirical	NOSSE Guide	1	15	21	.714
		2	16	21	.762
	NOS Examples	1	34	26	1.31
		2	35	26	1.35
Human Endeavor	NOSSE Guide	1	18	15	1.20
		2	12	15	0.80
		3	9	15	0.60
	NOS Examples	1	26	16	1.63
		2	16	16	1.00
		3	26	16	1.63
Data & Evidence	NOSSE Guide	1	6	8	.750
		2	13	8	1.63
		3	15	8	1.86
	NOS Examples*	1	14	8	1.75

Note. *The NOS Examples for data and evidence only had one viable group recording due to audio difficulty with the Livescribe ® pens.

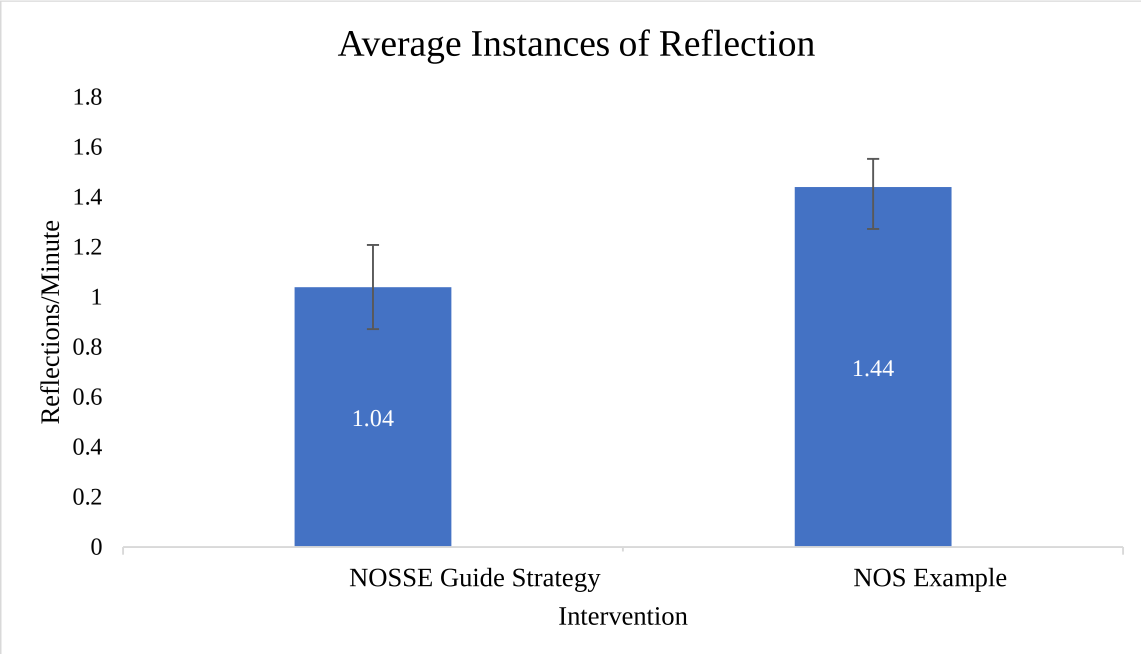

Figure 3.7. Average instances of reflection for intervention groups. Error bars represent standard errors.

Both intervention groups were asked to evaluate the NOSSE Guides. This activity prompted PSET in both intervention groups to reflect on aspects of NOS and SI. This was evident based on the following statements by the participants group as they grappled to make sense of the empirical nature of science using a NOSSE Guide:

> And this one [standard from NOSSE Guide] says not all questions can be answered by science. So I guess this is more of a morally correct science that we accept. 'Cause this says 'not all questions can be answered by science', and then down here it says 'science knowledge indicates that can happen in natural systems.' Not what should happen – 'the latter involves ethics, values, and human decisions about the use of knowledge'…I guess empirical is just basically what you can see and observe, and it says observations of the natural world…and

'beliefs about a particular idea will not be accepted by the scientific community unless it is supported.' So all empirical evidence has to have observations or experiments [pause]…which is understandable to me. (PSET in NOSSE ER Strategy Group 1, 10/5/16)

To me, what that [statement from NOSSE Guide] says is anything that is not a theory… there's no question, there's no guess…it is just what it is…'Scientific findings are limited to what can be answered with empirical evidence,' meaning what can be answered without question (PSET in NOS Example Group 2, 10/5/16).

Table 3.7

Types and Total Reflective Instances for Each Strategy by NOS/SI Aspect

NOS/SI Aspect	Strategy	PER	HES	DOU	SEAR	DEL	MM	RIG	REC	AFF	ALT
Empirical	NOSSE Guide	0	0	2	1	3	7	1	0	1	0
	NOSSE Guide	2	0	1	0	4	5	1	0	2	1
	Examples	4	1	5	5	4	7	2	1	3	2
	Examples	4	0	4	3	5	11	0	4	3	1
Total	NOSSE Guide	2	0	3	1	7	12	2	0	3	1
	Examples	8	1	9	8	9	18	2	5	6	3
Human Endeavor	NOSSE Guide	0	0	2	1	3	7	1	0	4	0
	NOSSE Guide	0	0	1	1	2	7	0	0	1	0
	NOSSE Guide	0	0	0	1	2	4	0	0	2	0
	Examples	0	1	2	1	5	9	1	3	4	0
	Examples	1	0	0	5	3	3	0	1	3	0
	Examples	0	0	0	2	7	4	3	1	9	0
Total	*NOSSE Guide*	0	0	3	3	7	18	1	0	7	0
	Examples	1	1	2	8	15	16	4	5	16	0
Data & Evidence	NOSSE Guide	0	0	1	0	0	2	3	0	0	0
	NOSSE Guide	0	0	2	0	0	8	0	0	3	0
	NOSSE Guide	1	0	2	0	0	6	2	2	1	1
	Examples	1	0	1	0	1	3	2	0	6	0

Note. Codes were: PER (perplexity), HES (hesitation), DOU (doubt), SEAR (searching), DEL (deliberation), MM (meaning-making), RIG (rigor of thinking), REC (reconsideration of existing knowledge), AFF (affirmation), ALT (alternative explanations). Totals were not calculated for Data & Evidence because the number of groups was not equal.

Types of Reflection

During each iteration of the intervention, the course instructor and researcher circulated among student groups in both sections to listen to small-group discourse.

Afterwards, we debriefed and agreed that there may be qualitative differences in the type and extent of reflection that occurred between the two groups as they engaged in their respective interventions. Based on classroom observations, it seemed that the small groups in the course section that engaged in the NOS Example Strategy debated and seemed to be perplexed and hesitant more often as they struggled to agree with where to place exemplar NOS responses along the continuum line. One group member would place an exemplar response card and then another group member would disagree about the placement. In many instances, someone in the group or the instructor and researcher would remind everyone to base the placements using the NOSSE Guide (science standards documents). Usually this would enable the group to come to consensus about card placements. One particular group was struggling to place the following exemplar responses on the continuum:

> Exemplar Response 1: Everything is science. You can't get through a whole day without solving a problem or sitting there wondering about something; and you can do that in every single discipline.
>
> Exemplar Response 2: Science is the study of everything.
>
> Exemplar Response 3: Science can be tested and other things like religion are based off faith and not tested.

The following dialogue provides an example of the type of deliberation and meaning making groups in the NOS Example Strategy group engaged in (among other types of reflection) as they struggled to come to consensus on card placements (NOS Example Group 2, 10/5/16). Classroom observations in conjunction with analysis of small-group discourse supported our claim that there were quantitative differences in the reflection that occurred in each intervention group (Table 3.7).

PSET 1: This makes me laugh: science is the study of everything. Everything. Mm hm.

PSET 2: Could be, though. Think about it. What are you studying in your next class? In my next class, I'm studying how, like, different standards of the Common Core affect math and how students' brains work with math. Well, studying the brain is science. When you think of it like that.

PSET 1: Mmm hm, I see what you're saying.

PSET 2: And knowing what works best for students. How does it work?

PSET 1: It's like, I think that…it [exemplar response 2] could have been worded better.

Researcher: I hear somebody saying 'I'm putting this one [exemplar response card] here' but [no one] provided an explanation. That explanation should come from where? Where do you get your justification?

PSET 1: The standards.

Researcher: Standards. Ok. So go ahead [and write the justification] on a large sticky for each of your placements.

PSET 2: So, yeah, I think maybe we should change this, huh? I mean, I just…we're having a debate about this.

Researcher: What's your debate? Use those standards documents.

PSET 1: Well, I mean, we feel like this is just not complete.

Researcher: Ok. What do you think they mean by everything?

PSET 1: Well, like…you were just talking about…like that was a really good example.

PSET 2: Like, in my next class, like we're going to be studying, it's math methods. But we're studying how, like, how the Common Core affects this person, but it might, like that standard will work for that person, but not for the next. And the only reason we know that is because we've studied the science of like how peoples' brains work, and everything. So, like even… I think when we did our one-on-one [VNOS follow-up interview], I kind of spoke on how everything is science.

Researcher: Ok.

PSET 2: Like even mowing your yard, you have to know how to do it. How do you know how to do it? It's because your brain is telling you, you have to…I don't know, I just feel like pretty much everything you do is science.

PSET 1: Mm kay. Science can be tested and other things, like religion, are based off faith. That is like a strange…

PSET 2: I think that's talking about how like, you know how people…

PSET 3: This [points to an exemplar response card]?

PSET 2: That's like, a standard they were talking about like evolution and stuff like that.

PSET 1: Ok, so, do we physically need to write out the standard?

PSET 2: Here, do you want to do a smaller sticky?

PSET 1: Yeah.

PSET 2: Ok, try that now.

PSET 3: I think that was saying that not all questions can be answered by science.

PSET 1: So that goes there?

PSET 3: Would that be…

PSET 1: What, where was it?

PSET 2: That would be [exemplar 2].

PSET 1: Ok. What does it [NOSSE Guide] say?

PSET 3: 'Not all questions can be answered by science.'

PSET 1: Not all questions can be answered with science. Ok…ok…

PSET 3: And then what's the next one?

PSET 1: 'Science can be tested and other things, like religion, are based off faith and not tested.'   So isn't that kind of the same standard as this one, that not all questions can be answered with science? 'Cause they're talking about religion as faith, you know, it can't really be…so let's stick these two together and they can share this. What do you say?

PSET 3: Ok. Yeah, makes sense.

Researcher: Why does it make sense, [PSET 3]?

PSET 3: Because, it's saying, well this [NOSSE Guide] says study of everything here.

PSET 2: It doesn't make sense to me.

PSET 3: No?

PSET 1: It doesn't.

PSET 2: Uh uh. Because this is not a question. And this standard is, is talking about all questions can be answered. This is just science…study of everything? I think we need to find something that talks about everything, rather than, well I guess not all. Since it has the word "all" in it, it wouldn't work.

PSET 1: So, we'll switch it to this. How about that?

PSET 2: I think this one should go with science, scientists study the natural and material world because the world is everything, natural and material. And that could be everything.

Initially, PSET 2 placed exemplar response 2 "science is the study of everything" as more like the standards documents (NOSSE Guide). Through reflective discourse and redirection to focus on the NOSSE Guide, this group of participants changed their placement of the exemplar response of "science is the study of everything" and "everything is science. You can't get through a whole day…" from more like the standards documents (NOSSE Guide) to less like, a move that demonstrated movement toward a more expert-like view of NOS. The final placements of the exemplar cards for this group are shown in Figure 3.8.

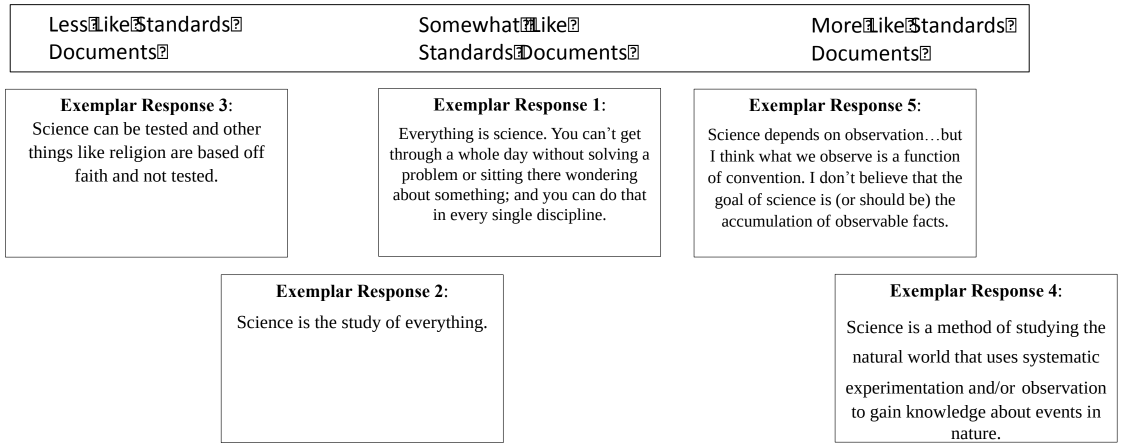

Figure 3.8. PSET Group 1 exemplar response card placements for the empirical NOS.

The NOSSE Guide ER Strategy group was directed to place cards that listed *course activities* according to whether the activity represented aspects of NOS and SI as described in the NOSSE Guides. In this manner, PSET were reflecting on the NOSSE Guide and coming to consensus about a card placement. However, when compared to the NOS Example Strategy groups, the NOSSE Guide ER Strategy groups engaged in reflective discourse with fewer instances of deliberation, perplexity, and doubt (Table 3.6). Indeed, participants in the NOSSE Guide ER Strategy had half as many reflective instances that were coded as deliberation as participants in the NOSSE Example Strategy group. Participants in the NOSSE Guide ER Strategy mainly focused on making meaning of NOS and SI aspects using text from the NOSSE Guides. The following quotes provide examples for the type of discourse that exemplifies how participants engaged in meaning-making of NOS and SI aspects.

> The quote [from the NOSSE Guide] also says evidence is interpreted data. But I said evidence is how you interpret data. (Participant in NOSSE Guide ER Strategy Group, 11/21/16).

> So this is what I think science is…what I can observe from being in school all my life. Science is a never-ending discovery of what the world can tell you. So with science you have to first come up with a question…and then you've got to see, ok, what evidence can help my question or what research can I look up to find my question? Because it's always evolving. (Participant, NOSSE Guide ER Strategy group discussing empirical NOSSE Guide, 10/5/16).

Overall, both interventions promoted PSET to reflect on NOS and SI aspects, enabling them to develop personal knowledge of both constructs. The NOS Example Strategy promoted more reflection than the NOSSE Guide ER Strategy. As reflection is a key change mechanism identified in the IMTPG framework, it is plausible that PSET in the NOS Example Strategy intervention may have experienced greater changes within the IMTPG personal domain, specifically for knowledge of NOS and SI and intentions to integrate NOS and SI. The following sections will present data to determine whether there were any statistically or practically significant changes within the IMTPG personal domain, starting with changes in PSET NOS and SI conceptions and then PSET intentions to integrate NOS in their future classroom instruction.

NOS & SI Conceptions

Research Question 2) What is the influence of the NOSSE Guide ER Strategy and NOS Example Strategy on PSET conceptions of NOS and SI?

Overall, both interventions prompted PSET to reflect on NOS and SI aspects, enabling them to develop more expert-like knowledge of both constructs (Table 3.8). The following section will compare the changes observed in NOS and SI knowledge (personal domain) by intervention group and by specific NOS and SI aspects. These aspects included a) the empirical nature of science, b) scientific knowledge is both tentative and durable, c) the distinction between observation and inference (science is a human endeavor), d) no single, step-wise scientific method for all investigations, e) data and evidence differ, and f) all investigations begin and are guided by the question asked. Due to time constraints, one aspect originally intended to be included in the study had to be excluded. This aspect, 'all investigations begin with and are guided by the question asked', was still assessed and used for comparison.

Table 3.8

Percentage of PSET With Informed NOS & SI Conceptions Before and After Instruction

	NOSSE Guide			*NOS Example*		
NOS/SI Aspect	Pre	Post	Change (%)	Pre	Post	Change (%)
Begins with Question	50%	50%	*0*	55%	85%	*+30*
Empirical NOS	67%	83%	*+16*	77%	91%	*+14*
Tentative yet Durable	8%	50%	*+42*	5%	41%	*+36*
Observation/ Inference	8%	83%	*+75*	5%	64%	*+59*
Data & Evidence	8%	50%	*+42*	9%	45%	*+36*
No Single Method	8%	42%	*+34*	10%	40%	*+30*

Professional Growth for NOS and SI: Changes in PSET Knowledge

A Wilcoxon signed-rank test was conducted to statistically examine changes in participants' pre and post VNOS-D and VOSI-270 responses in both the NOSSE Guide ER and NOS Example Strategy groups. The intervention targeted specific NOS and SI aspects, therefore, statistical results were reported by aspects (Table 3.9). PSET movement along NOS and SI conceptions, including both positive and negative shifts across three categories (naïve, mixed, and informed), were also visualized using professional growth diagrams (see Figure 3.9 as example below). Each number on the Figure represents the summed number of participants within each intervention group for each shift (e.g. naïve to mixed, etc.). The NOS Example Strategy participants are delineated in bold and underlined and the NOSSE Guide ER Strategy is not.

Positive growth indicates PSET gained more expert-like NOS and SI views and negative growth represents participants who regressed, moving back toward more naïve views. Professional growth diagrams should be interpreted by looking for patterns in the *location* of the numbers. Because there were more participants in the NOS Example Strategy group, this data is reported as percentages. Shifts toward more expert-like views are represented by numbers in the upper right quadrant. For example, participants could move as many as two categories (e.g., from naïve to informed) and this would be shown as a number in the far-right column of the figure (in the informed row). Likewise, shifts toward less expert-like views are represented by numbers in the lower left quadrant in the far-left column. For example, if a participant held a mixed view prior to the intervention and continued to hold this view afterward, this would be shown as a number in the center column at the mixed category on the y-axis. If a participant held an informed view at the outset of the course but regressed to a naïve view afterward, this would be shown as a number in the bottom row and the far-left column.

Table 3.9

Wilcoxon Signed Rank Statistical Test Results and Calculated Effect Size (r) for Pre-Post Changes in PSET Understandings

NOS or SI Aspect	Intervention	*T* statistic	*z*-Statistic	*p*	Effect size (*r*)
Empirical**					
	NOSSE Guide	14.0	0.816	.414	.17
	Examples	20.0	1.340	.257	.17
Tentative yet Durable***					
	NOSSE Guide	15.0	2.121*	.034	.43
	Examples	14.0	2.887*	.004	.44
Observations & Inferences**					
	NOSSE Guide	45.0	3.000*	.003	.64
	Examples	120	3.771*	.000	.57
No Single Scientific Method***					
	NOSSE Guide	45.0	2.810*	.005	.57
	Examples	61.5	2.652*	.008	.59
Data & Evidence Differ**					
	NOSSE Guide	28.0	2.530*	.011	.52
	Examples	84.5	3.000*	.003	.45
Investigations Begin with Questions[1]					
	NOSSE Guide	10.5	0.000	1.00	.00
	Examples	120	1.508	.132	.57

*Statistically significant difference within group from pre to post, $p < .05$. *T* statistic is the sum of the positive ranks. Effect size (r) was calculated by dividing test statistic (z-score) by the square root of the total number of observations (Field, 2013). **Intervention was a card sort activity completed during class time. ***Intervention occurred outside of class time as a take home assignment. [1]No intervention was conducted for 'investigations begin with questions.'

No Single Scientific Method

For PSET in the NOSSE Guide ER Strategy, their understanding that there is no single scientific method was statistically significantly higher after completing the biology course (M = 2.42, SD = .515, Mdn = 2.00) than at the beginning of the course, (M = 1.5; SD= .674, Mdn = 1.00), T = 45, p = .005, r = .57. Overall, participants showed positive growth, with 17% moving from naïve to informed views and another 17% shifting positively from mixed to informed views. Approximately 42% of participants in the

NOSSE Guide ER group held naïve views prior to the intervention but moved to mixed views after engaging in the strategy (Figure 3.9). Participants in the NOS Example Strategy group also improved their understanding that there is no single scientific method, as posttest scores were significantly higher after completing the biology course (M = 2.36, SD = .492, Mdn = 2.00) than at the beginning of the course, (M = 1.75, SD = .639, Mdn = 2.00), T = 61.5, p = .008, r = .59. This group showed overall positive shifts with 15% of participants moving from a naïve to an informed view and another 15% moving from a mixed to an informed view of this aspect. Effect sizes (r) were similar for each group and overall shifts toward more expert-like views are indicated by the large numbers in the upper right quadrant of the professional growth diagram (Figure 3.9).

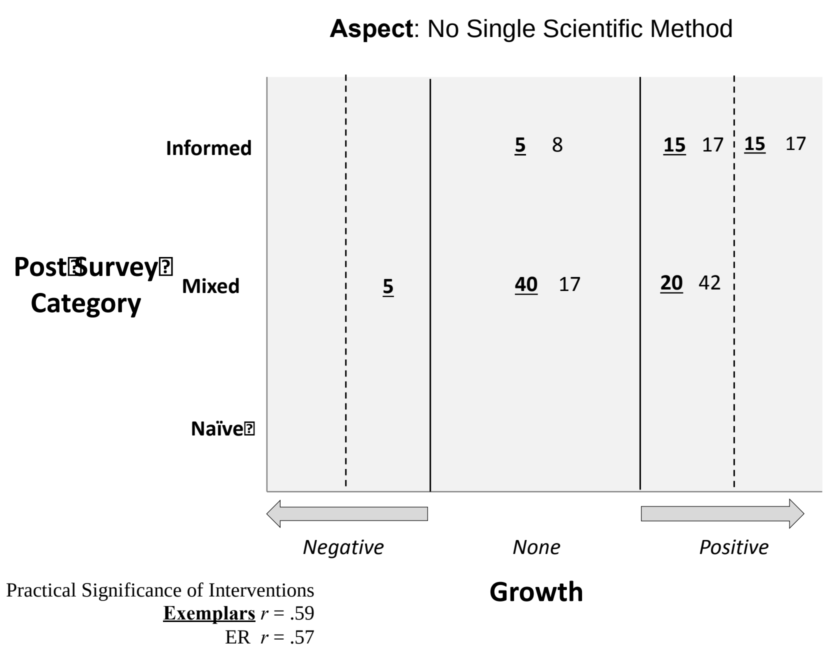

Figure 3.9. Professional growth diagram showing PSET shifts toward more expert-like views for no single scientific method in both intervention groups. Numbers are percentages. Bold and underlined numbers indicate participants in the NOS Example Strategy group.

Tentative Yet Durable NOS

For PSET in the NOSSE Guide ER Strategy condition, their understanding that scientific knowledge is tentative, yet durable, was statistically significantly higher after completing the biology course (M = 2.5, SD= .522, Mdn = 2.50) than at the beginning of the course, (M = 2.0, SD = .426, Mdn = 2.00), T = 15, p = .034, r = .43. The same was true for PSET in the NOS Example Strategy group, as their understanding of the tentative yet durable NOS changed and was significantly higher after completing the biology course (M = 2.41, SD = .503, Mdn = 2.50) than at the beginning of the course, (M = 1.95, SD = .375, Mdn = 2.00), T = 45, p = .004, r = .44. A total of thirteen participants in the NOS Example Strategy group (60%) and seven in the NOSSE Guide ER group (58%) did not show any growth for this aspect. Overall, participants in the NOS Example Strategy group shifted toward more expert-like views, with 32% of participants moving from mixed to informed views and another 5% moving from naïve to informed views after engaging in the intervention (Figure 3.10).

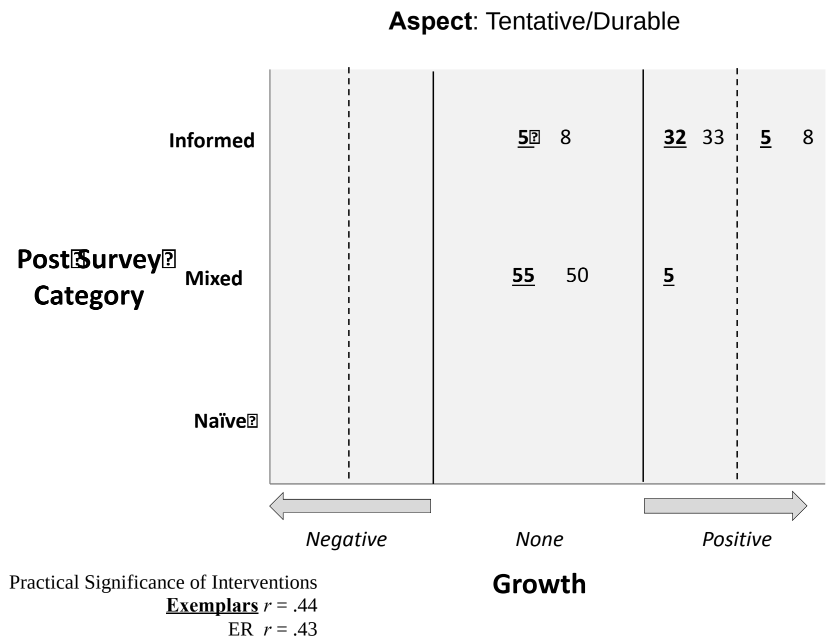

Figure 3.10. Professional growth diagram showing shifts toward expert-like views for the tentative yet durable NOS aspect, as indicated by large percentages in the upper right portion of the diagram. Numbers are percentages. Bold and underlined numbers indicate participants in the NOS Example Strategy group.

Empirical NOS

For PSET in the NOSSE Guide ER Strategy condition, their understanding that scientific knowledge is empirical was not statistically significantly different after completing the biology course (M = 2.83, SD = .389, Mdn = 3.00) than at the beginning of the course, (M = 2.67, SD =.492, Mdn = 3.00), T = 14, p = .414, r = .17. Sixty eight percent of participants in the NOSSE Guide ER Strategy group started and ended with informed views and 23% moved from mixed to informed after engaging in the intervention. Nine percent of participants showed negative shifts, moving from informed views to mixed views for this aspect (Figure 3.11). For PSET in the NOS Example Strategy group, their understanding of the tentative yet durable NOS did not change significantly from the beginning of the biology course (*M* = 2.77, *SD* = .429, *Mdn* = 3.00) to the end of the course, (*M* = 2.91, *SD*= .294, *Mdn* = 3.00), *T* = 20, *p* = .257, *r* = .17. Fifty percent of participants in this group started and ended with informed views and 8% moved from mixed to informed after engaging in the strategy. Sixteen percent of participants showed negative shifts, moving from informed views to mixed views for this aspect (Figure 3.11).

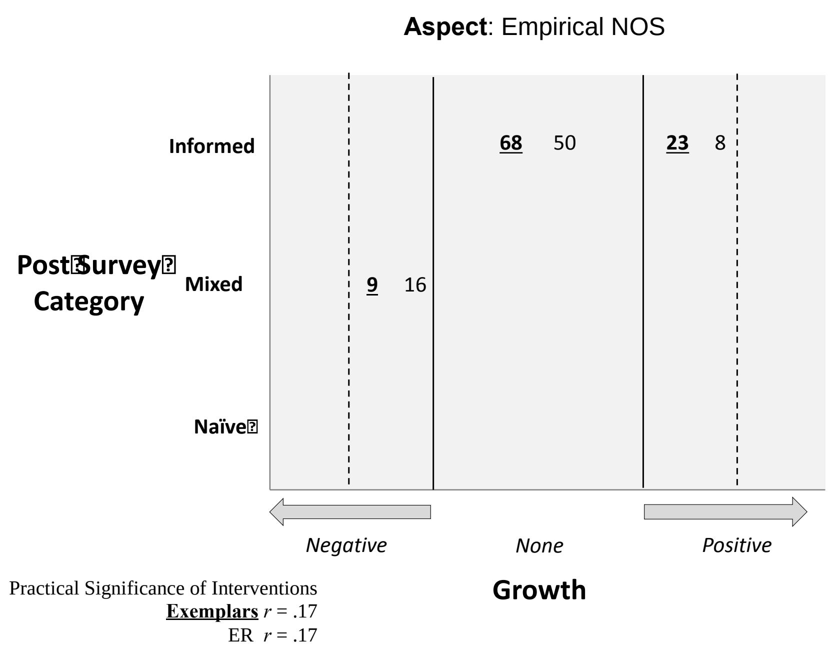

Figure 3.11. Professional growth diagram showing most participants began with informed views for the empirical NOS. Numbers are percentages. Bold and underlined numbers indicate participants in the NOS Example Strategy group.

Data and Evidence Differ

For PSET in the NOSSE Guide ER Strategy condition, their understanding that in science, data differs from evidence, was statistically significantly higher after completing the biology course (*M* = 2.42, *SD* = .669, *Mdn* = 2.50) than at the beginning of the course, (*M* = 1.75, *SD* =.622, *Mdn* = 2.00), *T* = 28, *p* = .011, *r* = .52. However, 8% of participants showed no growth, starting and ending with naïve views, and 25% started and ended with mixed views (Figure 3.12). In the NOS Example Strategy group, PSET understanding was statistically significantly higher after completing the biology course (*M* = 2.41 *SD* = .59, *Mdn* = 2.00) than at the beginning of the course, (*M* = 1.86, *SD* =.56, *Mdn* = 2.00), *T* = 84.5, *p* = .003, *r* = .45. Shifts toward more expert-like views were observed with 36% of participants moving from mixed to informed views and 5% moving from naïve to informed views, but 23% of participants in the NOS Example Strategy group continued to hold naïve views (Figure 3.12).

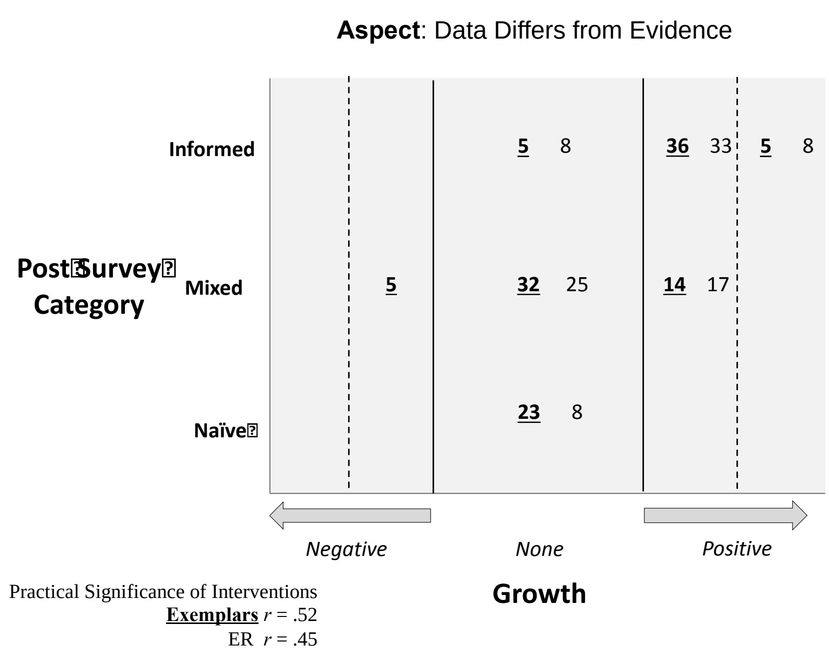

Figure 3.12. Professional growth diagram showing overall shifts toward expert-like views for the aspect data differs from evidence. Numbers are percentages. Bold and underlined numbers indicate participants in the NOS Example Strategy group.

Observations and Inferences

For PSET in the NOSSE Guide ER Strategy condition, their understanding that science is a creative endeavor based on observations and inferences was statistically significantly higher after completing the biology course (M = 2.83, SD = .389, Mdn = 3.00) than at the beginning of the course, (M = 2.09, SD = .302, Mdn = 2.00), T = 45, p = .003, r = .64. Eighty-two percent of participants shifted from holding mixed views to informed views after engaging in the intervention and 9% moved from holding naïve views to having informed views (Figure 3.13). The same was true for PSET in the NOS Example Strategy group, as their understanding was significantly higher after completing the biology course (M = 2.64, SD =.492, Mdn = 3.00) than at the beginning of the course, (M = 1.91, SD = .426, Mdn = 3.00), T = 120, p < .000, r = .57. Fifty-five percent of participants in the NOS Example Strategy group moved from mixed to informed views and 9% moved from naïve to mixed views. However, 27% showed no growth and retained a mixed view for this aspect (Figure 3.13).

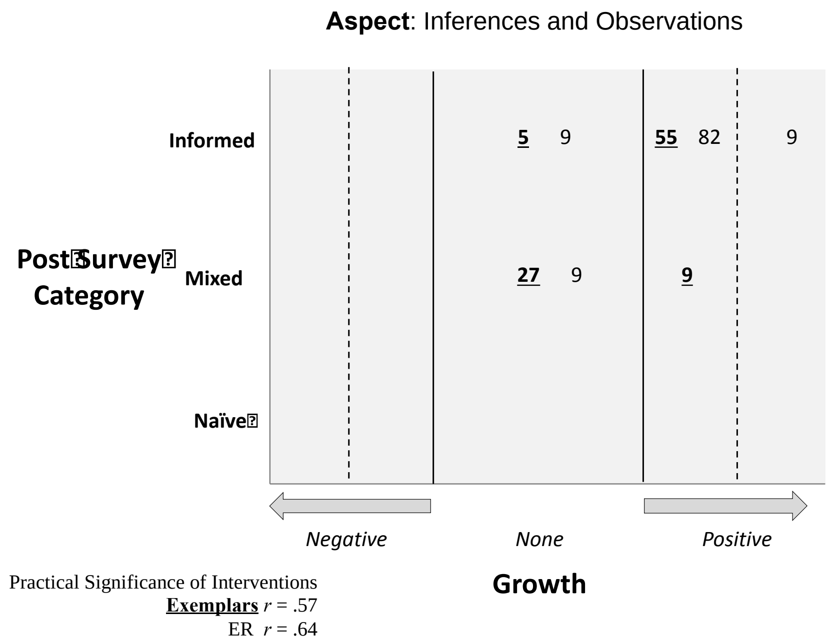

Figure 3.13. Professional growth diagram showing shifts toward expert-like views for distinguishing between observations and inferences. Numbers are percentages. Bold and underlined numbers indicate participants in the NOS Example Strategy group.

Scientific Investigations Begin with a Question

For PSET in the NOSSE Guide ER Strategy condition, their understanding that all scientific investigations begin with a question was not statistically significantly different after completing the biology course (M = 2.5, SD =.522, Mdn = 2.50) than at the beginning of the course, (M = 2.5, SD = .522, Mdn = 2.50), T = 10.5, p = 1.00, r = .00. PSET in the NOS Example Strategy group were not statistically significantly different after completing the biology course (M = 2.77, SD = .429, Mdn = 3.00) than at the beginning of the course, (M = 2.55, SD= .51, Mdn = 3.00), T = 48, p = .132, r = .57. Overall, most participants showed no professional growth for this aspect (Figure 3.14).

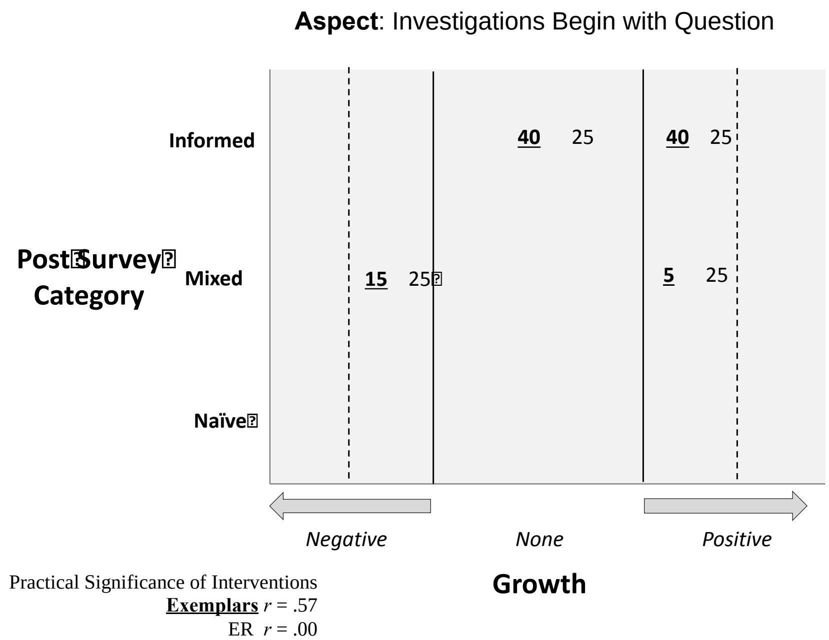

Figure 3.14. Professional growth diagram showing shifts toward and away from expert-like views. Numbers are percentages. Bold and underlined numbers indicate participants in the NOS Example Strategy group.

Overall, both interventions resulted in PSET professional growth toward more expert-like views of NOS and SI evidenced by small to medium effect sizes for each aspect addressed by the interventions. The NOS Example Strategy group, however, resulted in slightly larger effect sizes (r) for some aspects (Table 3.9). The aspect ‘all science investigations begin with a question’ was not addressed by either intervention. For the NOSSE Guide ER group there was no effect for this aspect but for the NOS Example group there was a moderate effect of $r = .57$.

Intentions to Integrate NOS

Research Question 3) What is the influence of the NOSSE Guide ER Strategy and NOS Example Strategy on PSET intentions to integrate NOS in future classroom instruction?

Each participants' item average for each of the seven factors determined as reliable in the exploratory factor analysis were averaged and compared pre-to post-intervention. A two-way, repeated measures ANOVA was conducted on each factor to determine if there were any statistically significant differences among factors between participants in the two intervention groups. The following section will describe differences between the intervention groups for the following variables: 1) teachers' readiness to integrate NOS into classroom instruction, 2) teachers' perception of the utility of NOS knowledge for students, 3) the pressure teachers' perceive to integrate NOS, 4) teachers' beliefs about factors they can control regarding NOS integration, 5) teachers' perceived important outcomes for NOS instruction, 6) teachers' beliefs about normative expectations to integrate NOS, and 7) teachers' overall attitudes about integrating NOS.

Table 3.10

Descriptive Statistics and Repeated Measures Analysis of Variance (ANOVA) Between Intervention Groups Over Time

			Pre		Post		Treatment		
Factors		n	M	SD	M	SD	*F*	*p*	*η*
1	Guide	12	6.48	.719	6.73	.345	5.295	.028	.142
	Examples	22	5.56	1.49	6.22	1.41			
2	Guide	12	4.78	1.23	4.77	1.40	2.531	.216	.073
	Examples	22	4.98	.975	5.55	.815			
3	Guide	11	5.52	1.08	6.05	1.11	0.131	.720	.004
	Examples	22	5.33	1.33	5.95	1.06			
4	Guide	11	5.93	.837	6.32	.672	0.194	.663	.006
	Examples	22	5.67	1.22	6.30	.981			
5	Guide	12	6.65	.458	6.71	.424	2.572	.119	.074
	Examples	22	6.03	1.41	6.50	.645			
6	Guide	11	6.09	.970	6.55	.611	.580	.452	.018
	Examples	22	5.75	1.40	6.41	.934			
7	Guide	12	6.24	.683	6.37	.675	.309	.582	.010
	Examples	22	6.10	.607	6.26	.739			

A two-way, repeated measures ANOVA was conducted to examine the effect of two ER NOS interventions over the course of a semester (Table 3.10). There was a statistically significant interaction between the effects of using an intervention using exemplars on PSET readiness to integrate NOS into their classroom instruction, $F(1, 32) = 5.295$, $p = .028$ (Figure 3.15). Simple main effects analysis showed that participants who received the ER NOS intervention that used examples perceived themselves as significantly more ready to integrate NOS instruction into their future classroom practice.

There was no statistically significant interaction between the effects of using an intervention that used examples on PSET perception of the utility of NOS knowledge for students, $F(1, 32) = 2.531$, $p = .216$ (Figure 3.16), on the pressure PSET perceive to integrate NOS, $F(1, 31) = 0.131$, $p = .720$ (Figure 3.17), on PSET beliefs about factors they can control regarding NOS integration, $F(1, 31) = 0.194$, $p = .663$ (Figure 3.18), on PSET perceived important outcomes for NOS instruction, $F(1, 32) = 2.572$, $p = .119$ (Figure 3.19), on PSET beliefs about normative expectations to integrate NOS, $F(1, 31) = .580$, $p = .452$ (Figure 3.20), or on PSET overall attitudes about integrating NOS, $F(1, 32) = .309$, $p = .582$ (Figure 3.21).

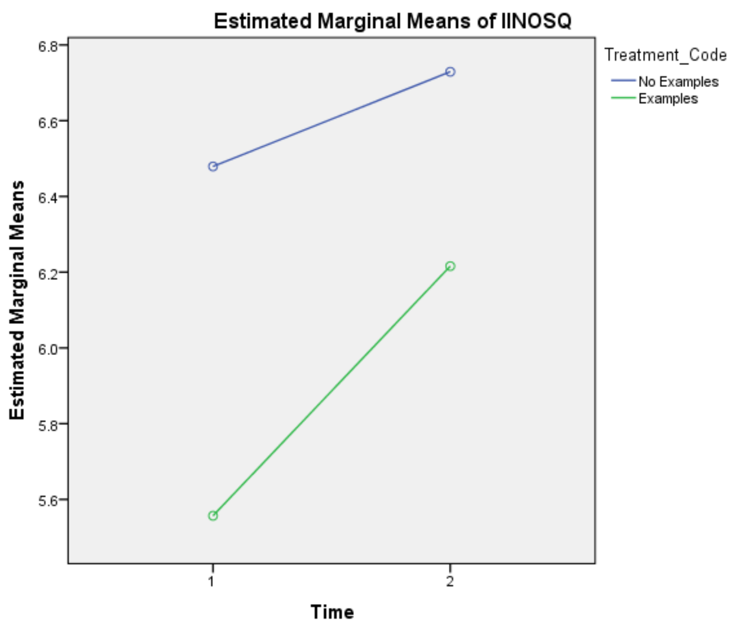

Figure 3.15. Profile plot showing statistically significant interaction for readiness to integrate NOS for PSET in NOS Example Strategy group.

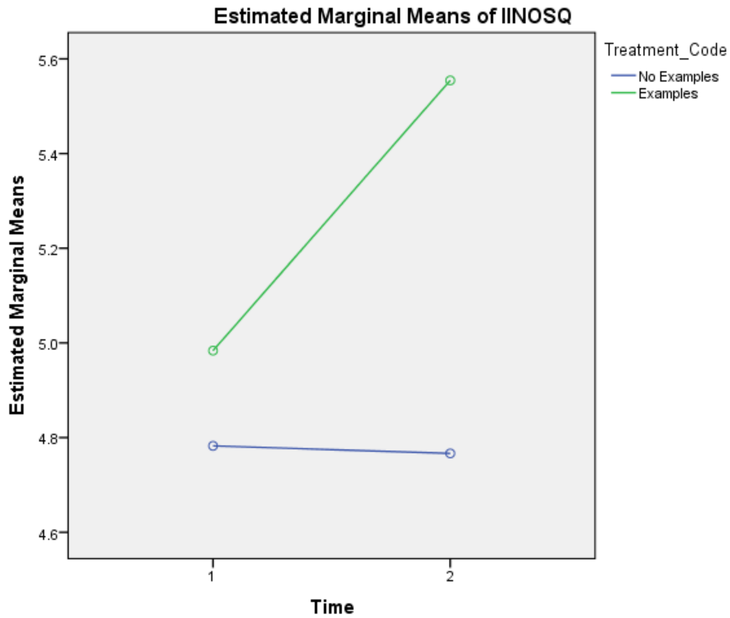

Figure 3.16. Profile plot showing no statistically significant interaction for PSET perception of NOS utility for students

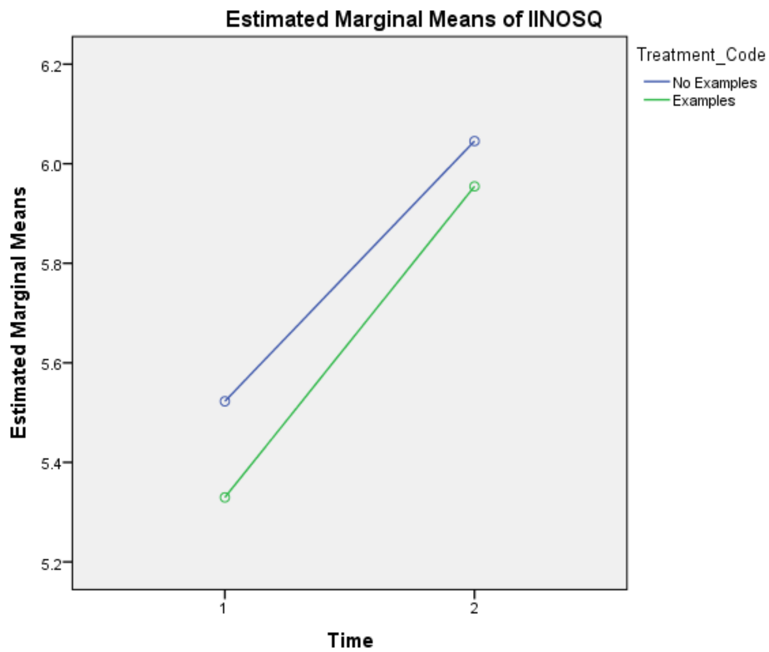

Figure 3.17. Profile plot showing no statistically significant interaction for PSET perceived pressure to integrate NOS

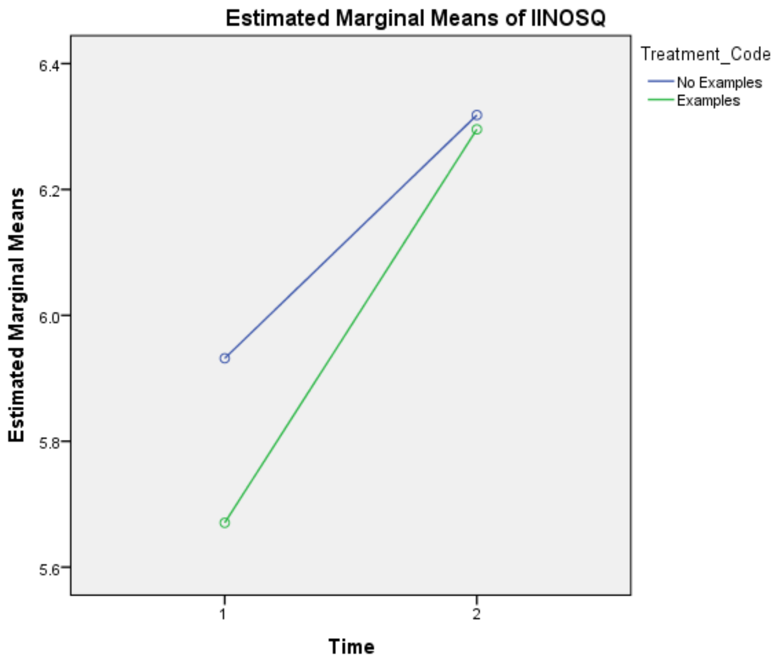

Figure 3.18. Profile plot showing no statistically significant interaction for PSET beliefs about factors they can control

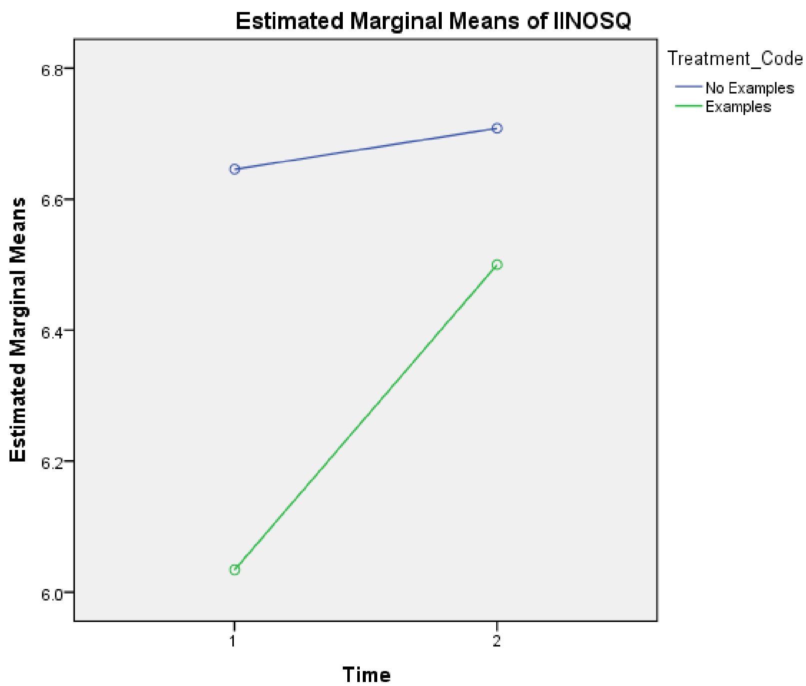

Figure 3.19. Profile plot showing no statistically significant interaction for PSET perceived important NOS outcomes

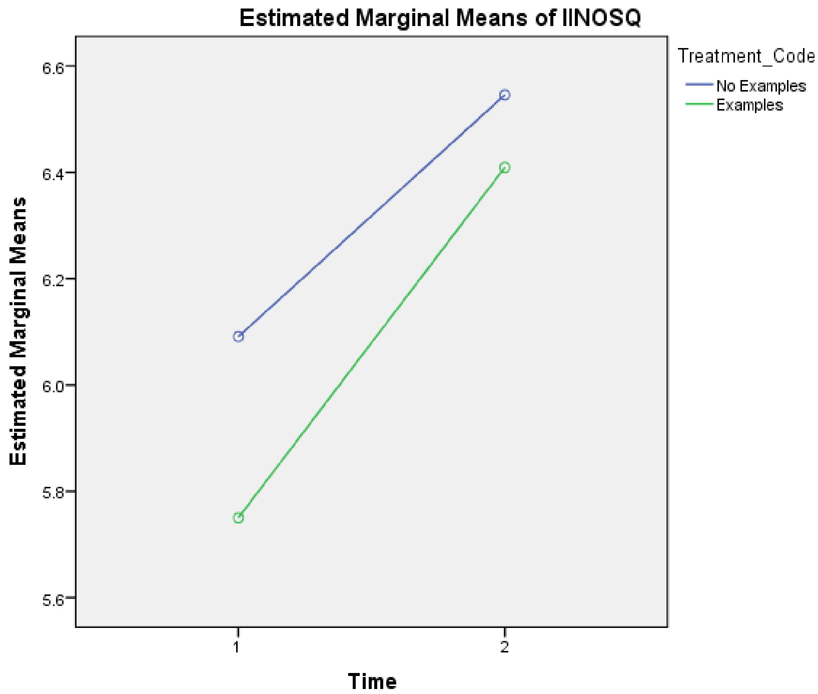

Figure 3.20. Profile plot showing no statistically significant interaction for PSET beliefs about normative expectations to integrate NOS

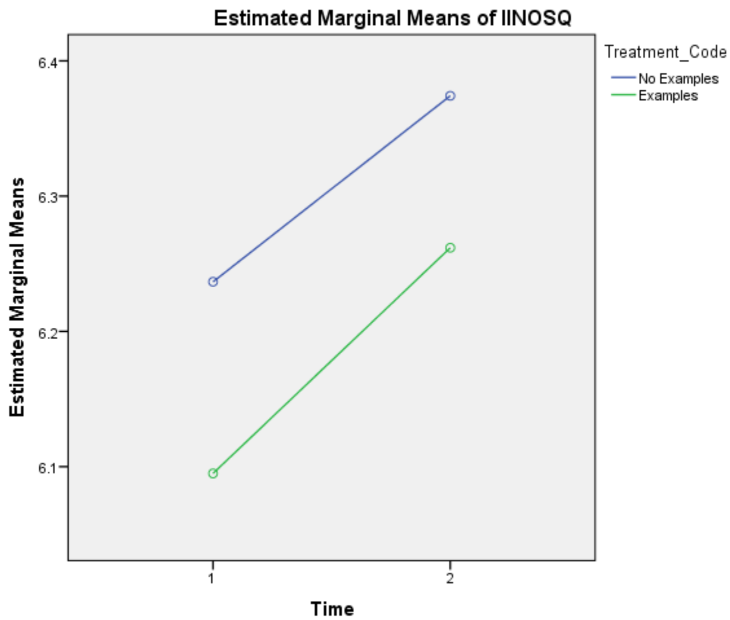

Figure 3.21. Profile plot showing no statistically significant interaction for PSET overall attitudes about integrating NOS

Overall, the ER NOS interventions implemented in the current study did not influence PSET intentions to integrate nature of science instruction in their future classroom practice. However, PSET in who engaged in the NOS Example Strategy did perceive themselves as more ready to integrate NOS into their future classrooms.

Discussion

A variety of ER approaches have been used to change teachers' NOS and SI conceptions. Whether some are more effective than others has not been systematically examined (see Chapter 2). In addition, Chapter 2 indicated some initial evidence of the benefits of ostention as a means to influence teacher professional growth for NOS and SI. Therefore, the current study included comparison groups in an attempt to parse out the influence of ostensive exemplars on PSET reflection, changes in conceptions of NOS and SI, and intentions to integrate NOS in future classroom instruction. Results indicated there were some differences in reflection, conceptions, and intentions as a result of using ostensive exemplars. As reflection has long been identified as a key process necessary to promote change in teachers' NOS conceptions (Abd-El-Khalick & Lederman, 2000), the first goal of this study was to examine the influence of each ER NOS intervention on PSET reflection. The next step was to determine whether the extent of PSET reflection influenced conceptions and intentions to integrate NOS (components of the personal domain in the IMTPG framework).

Reflection on NOS and SI

The NOSSE Guides used in this study were developed because NOS is not prominently featured in current science standards documents (e.g., NGSS). Each NOSSE Guide was developed around a guiding question for a specific NOS or SI aspect (Clough, 2007) and used to introduce PSET to expert-like views of specific aspects. Through small-group negotiation and reflective reasoning (Slade, 1995), PSET made collaborative decisions whether course activities or exemplar responses were representative of the expert-like conceptions of NOS and SI outlined in referent NOSSE Guides. Based on data collected, it was apparent both interventions used in the current study provided PSET with opportunities to reflect on their current understandings about NOS and SI through NOSSE Guides. The NOSSE Guides enabled PSET to confront discrepancies in their conceptions that arose when explicit information about NOS and SI was presented. In this regard, NOSSE Guides can serve as a resource science teacher educators can use to effectively integrate ER NOS instruction in the context of science courses.

Though NOSSE Guides promoted reflection in both groups, they may be more effective when used in conjunction with ostensive exemplars. Based on data from the current study, using ostensive exemplars to promote reflection resulted in more teacher reflection between the two groups. While both groups' discussion showed numerous instances of reflection (specifically through meaning-making), participants in the NOS Example group exhibited more instances of reflection. While this difference was not statistically significantly different, the overall difference was practically significant (d = 1.07). This could be further explored to determine if using ostensive examples consistently promotes more reflection on NOS and SI aspects. Also, participants in the NOS Example Strategy group debated and were more hesitant and perplexed while placing exemplars. The coding framework developed for this dissertation may be useful in future studies to qualitatively examine reflective discourse that occurs when teachers engage in ER NOS interventions.

One explanation for the differences observed in this study could be that PSET who reflected on exemplars saw their own conceptions reflected within particular exemplar responses. This resulted in hesitation and perplexity, specifically when there was a contradiction between a naïve exemplar they identified with and the expert-like view contained within the NOSSE Guides. For example, PSET dialogue showed how one group engaged in the NOS Exemplar Strategy debated the placement of the exemplar response "science is the study of everything." One group member identified with the exemplar and provided examples from her experience to support that science *was* the study of everything (a naïve view). However, another group member who disagreed responded by asking the entire group to examine the NOSSE Guide. Together, the group found the statement, ‘Not all questions can be answered by science’ in the NOSSE Guide and decided to move their original exemplar placement closer to the “less-like” side of the continuum. The student who originally identified with the naïve exemplar response agreed to this new placement. This type of reflective discourse enabled participants to learn from one another and likely made aspects of NOS and SI even more explicit (Yacoubian & BouJaoude, 2010). Careful examination and reflection on contrasting exemplar responses, particularly those that participants identified with as similar to their own, gave PSET the opportunity to more extensively "re-evaluate and re-form personal theories" (Abell & Bryan, 1997, p.162) for NOS and SI and may have resulted in more reflective discourse than occurred in the NOSSE Guide ER Strategy group.

NOS and SI Conceptions

Even though there were differences observed between the two groups regarding the extent and nature of the reflective discourse, this did not result in overall statistically significant differences regarding PSET development of NOS and SI conceptions. At the conclusion of the study, both intervention groups showed professional growth for NOS and SI conceptions (Table 3.8). This was expected, as including explicit and reflective discussion about NOS has been found to be an effective means to improve NOS conceptions (Akerson, Abd-El-Khalick, & Lederman, 2000; Yacoubian & BouJaoude, 2010, among others). However, there were some subtle differences in changes observed among specific aspects of NOS and SI. For example, when compared across aspects, PSET showed the most growth regarding observations and inferences. A large percentage of participants in both intervention groups shifted from a mixed view to an informed view (Figure 3.13). This result should be interpreted with caution, as this shift may be explained by the inclusion of the decontextualized NOS activity, Tricky Tracks (Abd-El-Khalick and Lederman, 1998), unexpectedly being taught by the course instructor in addition to the interventions implemented by the researcher. The extra instructional time on this aspect, not the interventions, likely accounted for the greater changes in this aspect as compared to others.

While there was little growth for the empirical NOS, the professional growth charts for this aspect show that the majority of participants started with and retained informed views (Figure 3.11). This may be explained by the explicit instruction of this aspect by the course instructor that occurred on the same day participants completed the preassessment. Some studies have indicated teachers' understandings improve differentially for some NOS and SI aspects (Demirdogen & Uzuntiryaki-Kondakci, 2016; Kucuk, 2008; Mesci & Schwartz, 2017; Mulvey & Bell, 2016). Therefore, closer examination of which aspects are more resistant to change for PSET during ER NOS instruction is an area of inquiry that could be explored further.

Both interventions included guidelines for conceptual change (Hewson et al., 1998), which may provide an additional explanation for why participants in both intervention groups showed positive shifts toward more expert-like views of NOS and SI (Table 3.11).

Table 3.11

How Both ER NOS Interventions Meet Guidelines for Conceptual Change

Guideline (Hewson et al., 1998)	ER NOS Intervention
Participant and instructor ideas about NOS and SI are made an explicit part of classroom discourse	NOSSE Guides make NOS and SI explicit and are focal point of whole-class and small group discussion.
Discourse is metacognitive and metaconceptual	Placing exemplar responses or course activity cards required participants to describe their thinking about the placement of the cards.
Status of ideas is discussed and negotiated	Participants were required to discuss and negotiate whether course activities and/or exemplar responses were ‘more-like’ or ‘less-like’ along a continuum when compared to the expert-like view portrayed by the NOSSE Guide.
Curriculum requires ideas and status decisions to be justified	Participants were required to justify all placements with evidence from the NOSSE Guides along with what they had learned in the biology course.

It is possible that while reflective and metacognitive discourse occurred within each intervention group, this discourse was not distinct enough to result in observable differences. Indeed, Ward and McCotter (2004) noted that it is “unusual and difficult” (p. 255) for PSET to reach transformative levels of reflection, making it plausible that the extent of reflective and metacognitive discourse observed in both groups was not sufficient to result in extensive changes in NOS and SI conceptions. It was beyond the scope of this study to examine individual participant cases, though examining individual participant reflection and specific group dynamics (i.e., individuals who reflect more or qualitatively different than other group members; participant engagement) may further identify factors associated with changes in NOS and SI conceptions. (See Chapter 4 for an example of a study that does this).

Intentions for Integrating NOS into Classroom Instruction

Teachers' intent to integrate NOS into classroom instruction is thought to be an important factor mediating the translation of NOS conceptions into teaching practices (Lederman, Schwartz, & Abd-El-Khalick, 2001). While the PSET in the current study did not have a context in which to integrate NOS instruction (as they were preservice teachers), the recent development of the Intentions to Integrate Nature of Science Questionnaire (Akyol, et al., 2016) enabled the researcher to determine if either ER NOS intervention resulted in changes in PSET future intentions to integrate NOS into their classrooms. For the most part, participant's intentions regarding NOS did not change as a result of engaging in ER NOS instruction. However, PSET in the intervention group that used ostensive exemplars perceived themselves as significantly more ready to integrate NOS instruction in their future classroom practice. Could there be something unique about using ostensive exemplars that boosted PSET self-efficacy and therefore perception of their own intent to integrate NOS into future instruction? This question was not examined in the current study but could be explored in future studies.

Limitations

Most studies that have examined ER NOS strategies have been short in nature (one semester or less). However, studies that have been longer in nature (Lederman, Lederman, Kim, and Ko, 2012; Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001; Donnelly & Argyle, 2011) may be more successful to change teachers' conceptions.

Participants in the current study engaged in their respective interventions a total of 85 minutes spread over the course of the entire semester. This duration may be too short of a time to result in lasting changes in conceptions and may have influenced the levels of change observed in the variables examined in this study. Future implementation and testing of either intervention should engage participants longer and include a delayed post assessment to determine whether participants' views of NOS are retained long-term (see Chapter 2).

The amount of time required for participants to take the pre and post survey assessments for this study was a concern for the course instructor. Therefore the pre assessments were divided and administered over the course of a week. During this time participants received science content that was related to NOS and SI aspects (e.g., the empirical nature of scientific knowledge, the difference between observations and inferences). Future studies should ensure that the pre assessments are completed prior to any science instruction.

Lastly, the coding scheme developed for this study was developed by the researcher and only the researcher coded small group discourse for instances of reflection. The validity of coded discourse would be improved by including a measure of inter-rater reliability in future analysis of this data.

Conclusion

Improving teachers' NOS conceptions is a complex and difficult endeavor. Even when ER approaches are used over extended periods of time, teachers' conceptions may be resistant to change (Akerson, Cullen, & Hanson, 2009). There are many ER NOS strategies that have been used to promote teacher professional growth for NOS and SI (see Chapter 2). The current study examined the use of two novel ER NOS strategies that incorporated the use of NOSSE Guides to make aspects of NOS and SI clear and explicit to teachers. Use of NOSSE Guides resulted in teacher professional growth for NOS and SI provided science teacher educators with a much-needed resource to include ER NOS instruction in their own classrooms. Using ostensive exemplars enhanced PSET reflection on NOS and SI aspects, but more research is needed to determine whether this approach is more effective than other more commonly used approaches, such as incorporating decontextualized and contextualized NOS and SI activities into PSET courses.

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APPENDICES

APPENDIX 3.A

Intent to Integrate NOS Questionnaire

What is nature of science? Nature of science refers to the characteristics of scientific knowledge and describes science as a way of knowing about the natural world. Nature of science includes aspects of the history and philosophy of science.

Dear Pre-Service Teacher,

This study intends to determine your views on "**integrating nature of science into science instruction**". Please read each sentence carefully, and then check the appropriate option. Some questions in this questionnaire are similar to others, do not worry about it.

Thank you in advance for your contribution.

Items related to Intention:

Considering your own teaching, to what extent do you agree with the following statements?	Strongly Disagree 1	2	3	4	5	6	Strongly Agree 7
I will try to integrate nature of science into science instruction	☐	☐	☐	☐	☐	☐	☐
I plan to integrate nature of science into science instruction	☐	☐	☐	☐	☐	☐	☐
I intend to integrate nature of science into science instruction	☐	☐	☐	☐	☐	☐	☐

Items related to Attitude:

For me, to integrate nature of science into science instruction is ...								
	7	6	5	4	3	2	1	
Useful	☐	☐	☐	☐	☐	☐	☐	Useless
Important	☐	☐	☐	☐	☐	☐	☐	Unimportant
Valuable	☐	☐	☐	☐	☐	☐	☐	Worthless
Correct	☐	☐	☐	☐	☐	☐	☐	Incorrect
Reasonable	☐	☐	☐	☐	☐	☐	☐	Unreasonable
Worthwhile	☐	☐	☐	☐	☐	☐	☐	A waste of time

Items related to behavioral belief strength:

If I integrate nature of science into science instruction:	1 Strongly Disagree	2	3	4	5	6	7 Strongly Agree
Students easily understand science topics	☐	☐	☐	☐	☐	☐	☐
Students understand the interaction among science, technology, society, and environment better	☐	☐	☐	☐	☐	☐	☐
Students are raised as critical thinkers	☐	☐	☐	☐	☐	☐	☐
Students differentiate science (physics, chemistry, biology) from other disciplines (e.g., history, philosophy)	☐	☐	☐	☐	☐	☐	☐
Students distinguish between science and pseudoscience (e.g., astrology, acupuncture)	☐	☐	☐	☐	☐	☐	☐
Students realize that science is part of everyday life	☐	☐	☐	☐	☐	☐	☐
Students' misconceptions related to nature of science are eliminated	☐	☐	☐	☐	☐	☐	☐
Students realize that scientists are not different from other people	☐	☐	☐	☐	☐	☐	☐
Students start to critically evaluate scientific news in the media	☐	☐	☐	☐	☐	☐	☐
I become professionally developed	☐	☐	☐	☐	☐	☐	☐

Items related to outcome evaluation:

How important to you are the following situations?	1 Not important at all	2	3	4	5	6	7 Very important
That students easily understand science topics	☐	☐	☐	☐	☐	☐	☐
That students understand the interaction among science, technology, society, and environment better	☐	☐	☐	☐	☐	☐	☐
Development of students as critical thinkers	☐	☐	☐	☐	☐	☐	☐
That students differentiate science (physics, chemistry, biology) from other disciplines (e.g., history, philosophy)	☐	☐	☐	☐	☐	☐	☐
That students distinguish between science and pseudoscience (e.g., astrology, acupuncture)	☐	☐	☐	☐	☐	☐	☐
That students realize that science is part of everyday life	☐	☐	☐	☐	☐	☐	☐
Eliminating students’ misconceptions related to nature of science	☐	☐	☐	☐	☐	☐	☐
That students realize scientists are not different from other people	☐	☐	☐	☐	☐	☐	☐
That students start to critically evaluate scientific news in the media	☐	☐	☐	☐	☐	☐	☐
Developing myself professionally	☐	☐	☐	☐	☐	☐	☐

Items related to subjective norm:

To what extent do you agree with the following statements?	1 Strongly Disagree	2	3	4	5	6	7 Strongly Agree
People/Institutions whose opinions I value expect me to integrate nature of science into science instruction	☐	☐	☐	☐	☐	☐	☐
Most of the people/institutions that I think to be important to my teaching career expect me to integrate nature of science into science instruction	☐	☐	☐	☐	☐	☐	☐
Most people who are important to me will be disappointed if I do not integrate nature of science into science instruction	☐	☐	☐	☐	☐	☐	☐

Items related to normative belief strength:

The following people/institution expect me to integrate nature of science into science instruction:	1 Strongly Disagree	2	3	4	5	6	7 Strongly Agree
Department of Education	☐	☐	☐	☐	☐	☐	☐
Faculty members	☐	☐	☐	☐	☐	☐	☐
School administrators	☐	☐	☐	☐	☐	☐	☐
Science teachers	☐	☐	☐	☐	☐	☐	☐

Items related to motivation to comply:

How important are expectations of people or institution related to your integration of nature of science into your science instruction for you?	Not important at all 1	2	3	4	5	6	Very important 7
Department of Education	☐	☐	☐	☐	☐	☐	☐
Faculty members	☐	☐	☐	☐	☐	☐	☐
School administrators	☐	☐	☐	☐	☐	☐	☐
Science teachers	☐	☐	☐	☐	☐	☐	☐

Items related to perceived behavioral control:

To what extent do you agree with the following statements?	Strongly Disagree 1	2	3	4	5	6	Strongly Agree 7
For me to integrate nature of science into science instruction is possible	☐	☐	☐	☐	☐	☐	☐
For me to integrate nature of science into science instruction is easy	☐	☐	☐	☐	☐	☐	☐
To integrate nature of science into science instruction is up to me	☐	☐	☐	☐	☐	☐	☐
I can overcome any problems that could prevent me from integrating nature of science into science instruction if I want to	☐	☐	☐	☐	☐	☐	☐

Items related to control belief strength:

During your in-service teaching career, to what extent do you expect the following factors will be present?	Not possible at all 1	2	3	4	5	6	Certainly possible 7
I will have sufficient knowledge of nature of science	☐	☐	☐	☐	☐	☐	☐
I will have experience for integrating nature of science into science instruction	☐	☐	☐	☐	☐	☐	☐
I will be sufficient in integrating nature of science in science instruction	☐	☐	☐	☐	☐	☐	☐
I will be able to use appropriate teaching strategies to effectively integrate nature of science into science instruction	☐	☐	☐	☐	☐	☐	☐

Items related to power of control factor:

The presence of the following factors will facilitate integrating nature of science into science instruction:	Strongly Disagree 1	2	3	4	5	6	Strongly Agree 7
My having sufficient knowledge of nature of science	☐	☐	☐	☐	☐	☐	☐
My having experience for integrating nature of science into science instruction	☐	☐	☐	☐	☐	☐	☐
My being sufficient in integrating nature of science in science instruction	☐	☐	☐	☐	☐	☐	☐
My ability to use appropriate teaching strategies to effectively integrate nature of science	☐	☐	☐	☐	☐	☐	☐

Intention to Integrate Nature of Science Questionnaire Items Retained for Factor Analysis

Item	Intention to Integrate NOS Questionnaire Item
Readiness	
1	Considering your own teaching, to what extent do you agree with the following statement? I will try to integrate nature of science into science instruction.
2	Considering your own teaching, to what extent do you agree with the following statement? I plan to integrate nature of science into science instruction.
3	Considering your own teaching, to what extent do you agree with the following statement? I intend to integrate nature of science into science instruction.
4	How important to you is the following situation? That students start to critically evaluate scientific news in the media.
Utility	
5	If I integrate NOS into science instruction: Students easily understand science topics.
6	If I integrate NOS into science instruction: Students understand the interaction among science, technology, society, and environment better.
7	If I integrate NOS into science instruction: Students are raised as critical thinkers.
8	If I integrate NOS into science instruction: Students differentiate science (physics, chemistry, biology) from other disciplines (e.g., history, philosophy).
9	If I integrate NOS into science instruction: Students distinguish between science and pseudoscience (e.g., astrology, acupuncture).
10	If I integrate NOS into science instruction: Students realize that science is part of everyday life .
11	If I integrate NOS into science instruction: Students' misconceptions related to nature of science are eliminated.
12	If I integrate NOS into science instruction: Students realize that scientists are not different from other people.
13	If I integrate NOS into science instruction: Students start to critically evaluate scientific news in the media.
14	If I integrate NOS into science instruction: I become professionally developed.
Subjective Norms (Pressure)	
15	To what extent do you agree with the following statement? People/Institutions whose opinions I value expect me to integrate nature of science into science instruction.
16	To what extent do you agree with the following statement? Most of the people/institutions that I think to be important to my teaching career expect me to integrate nature of science into science instruction.
17	To what extent do you agree with the following statement? Most people who are important to me will be disappointed if I do not integrate nature of science into science instruction.
18	Rate how you agree or disagree with the following people/institution expect me to integrate NOS into science instruction: Department of Education

Control Beliefs	
19	During your in-service teaching career, to what extent do you expect the following factors will be present? I will have sufficient knowledge of nature of science.
20	During your in-service teaching career, to what extent do you expect the following factors will be present? I will have experience for integrating nature of science into science instruction.
21	During your in-service teaching career, to what extent do you expect the following factors will be present? I will be sufficient in integrating nature of science in science instruction.
22	During your in-service teaching career, to what extent do you expect the following factors will be present? I will be able to use appropriate teaching strategies to effectively integrate nature of science into science instruction.
Instructional Outcomes	
23	How important to you is the following situation? That students easily understand science topics.
24	How important to you is the following situation? That students realize that science is part of everyday life.
25	How important to you is the following situation? Eliminating students' misconceptions related to nature of science.
26	How important to you is the following situation? That students realize scientists are not different from other people.
Normative Beliefs (Expectations)	
27	The following people/institution expect me to integrate NOS into science instruction: School administrators.
28	The following people/institution expect me to integrate NOS into science instruction: Science teachers.
Attitudes	
29	For me, to integrate nature of science into instruction is: Useful/Useless
30	For me, to integrate nature of science into instruction is: Important/Unimportant
31	For me, to integrate nature of science into instruction is: Valuable/Worthless
32	For me, to integrate nature of science into instruction is: Correct/Incorrect
33	For me, to integrate nature of science into instruction is: Reasonable/Unreasonable
34	For me, to integrate nature of science into instruction is: Worthwhile/A waste of time
35	How important to you is the following situation? That students understand the interaction among science, technology, society, and environment better.
36	To what extent do you agree with the following statement? For me to integrate nature of science into science instruction is possible.
37	To what extent do you agree with the following statement? For me to integrate nature of science into science instruction is easy.
38	To what extent do you agree with the following statement? I can overcome any problems that could prevent me from integrating nature of science into science instruction if I want to.
39	The presence of the following factors will facilitate integrating NOS into science instruction: My having sufficient knowledge of NOS.
40	The presence of the following factors will facilitate integrating NOS into science instruction: My having experience for integrating NOS into science instruction.

Note. For attitude items, participants selected degree of attitude, 7 to 1.

APPENDIX 3.B

Abridged VNOS, VOSI, & VASI SURVEY QUESTIONS

NAME: Date:

Instructions

- Please answer each of the following questions. You can use all the space provided and the backs of the pages to answer a question.
- Some questions have more than one part. Please make sure you write answers for each part.
- There are no "right" or "wrong" answers to the following questions but you should support your response with examples or experiences from Biology 3000. I am only interested in your ideas relating to the following questions. If you have any question or need clarification please ask.

1. What, in your view, is **science**? How can you determine when something is science (such as biology or physics) and when something is not science (such as religion or philosophy)?

2. What makes science (or a scientific discipline such as physics, biology, etc.) different from other subject/disciplines (art, history, philosophy, etc.)?

3. Scientists produce scientific knowledge. Do you think this knowledge may change in the future? Explain your answer and give an example.

4. In order to predict the weather, weather persons collect different types of information. Often they produce computer models of different weather patterns.
   a) Do you think weather persons are certain (sure) about the computer models of the weather patterns?

   b) Why or why not?

5. The model of the inside of the Earth shows that the Earth is made up of layers called the crust, upper mantle, mantle, outer core and the inner core. Does the model of the layers of the Earth *exactly* represent how the inside of the Earth looks? Explain your answer.

6. After scientists have developed a scientific theory (e.g., atomic theory, cell theory, evolution theory), does the theory ever change? Explain and give an example.

7. (a) How do scientists know that dinosaurs really existed? Explain your answer.

   (b) How certain are scientists about the way dinosaurs looked and moved? Explain your answer.

   (c) Scientists agree that about 65 millions of years ago the dinosaurs became extinct. However, scientists disagree about what caused this extinction. Why do you think they disagree even though they all have the <u>same</u> information?

   (d) If a scientist wants to persuade other scientists of their theory of dinosaur extinction, what do they have to do to convince them? Explain your answer.

8. What types of activities do scientists (e.g., biologists, chemists, physicists, earth scientists) do to learn about the natural world? Discuss how scientists (biologists, chemists, earth scientists) do their work.

9. A lot of science relies on terminology. We'd like to know how you understand and use some of common terms in science.

(a) What do you think a scientific experiment is? Give an example to support your answer

(b) Does the development of scientific knowledge require experiments?

- <u>If yes</u>, explain why. Give an example to defend your position.
- <u>If no</u>, explain why. Give an example to defend your position.

(c) What does the word "data" mean in science?

(d) Do you think "data" the same or different from "evidence" ? Explain.

10. Models are widely used in science. What is a scientific model? Describe and give an example.

A scientific model is….

Give an example of a model:

11. A person interested in animals looked at hundreds of different types of animals who eat either meat or plants. He noticed that those animals who eat similar types of food tend to have similar teeth structures. For example, he noticed that meat eaters, such as lions and coyotes, tend to have teeth that are sharp and jagged. They have large canines and large, sharp molars. He also noticed that plant eaters, such as deer and horses, have smaller or no canines and broad, lumpy molars. He concluded that there is a relationship between teeth structure and food source in the animals.

(a) Do you consider this person's investigation to be an experiment? Please explain why or why not.

(b) Do you consider this person's investigation to be scientific? Please explain why or why not by describing what it means to do something "scientifically."

This investigation is / is not (circle one) scientific because….

12. The "scientific method" is often described as involving the steps of making a hypothesis, identifying variables (dependent/independent), designing an experiment, collecting data, reporting results. Do you agree that to do good science, scientists must follow the scientific method?

______YES, scientists must follow the scientific method

_______NO, there are many scientific methods

- If YES (you think all scientific investigations must follow a standard set of steps or method), describe why scientists must follow this method.

- If NO (you think there are multiple scientific methods), explain how the methods differ and how they can still be considered scientific.

13. Two students are asked if scientific investigations must always begin with a scientific question. One of the students says "yes" while the other says "no". Whom do you agree with and why?

Give an example.

14. Two teams of scientists are walking to their lab one day and they saw a car pulled over with a flat tire. They all asked, “Are different brands of tires more likely to get a flat?”

    - Team A went back to the lab and tested various tires’ performance on three types of road surfaces.
    - Team B went back to the lab and tested one tire brand on three types of road surfaces.

    Explain why one team’s procedure is better than the other one.

Minutes of Light Each Day	Plant Growth (height in cm per week)
0	25
5	20
10	15
15	10
20	5
25	0

15. The data table above shows the relationship between plant growth in a week and the number of minutes of light received each day. Given this data, explain which of the following conclusions you agree with and why.

I agree with (please circle and then explain in the space provided):

Plants grow taller with more sunlight.

Plants grow taller with less sunlight.

The growth of plants is unrelated to sunlight.

Are the data what you expected? Why or why not?

APPENDIX 3.C

NOSSE GUIDES & PROMPTS

NOSSE GUIDE: NO SINGLE SCIENTIFIC METHOD
Guiding Question: How does the notion of a scientific method distort how science actually works? How does it accurately portray aspects of how science works? (Clough, 2007)

Science Aspects for Teaching Elementary Students

- There is no single, set scientific method
- Students collect, discuss, and communicate findings from a variety of investigations *(TN Science Standards, Kindergarten)*
- Science investigations use a variety of methods, tools, and techniques and scientists use different ways to study the world (Next Generation Science Standards)
- The idea that a common series of steps is followed by all research scientists must be one of the most pervasive myths of science and is often included in text books *(Bill McComas, Science Educator)*
- The National Science Teachers Association recommends that teachers help students understand there is no fixed sequence of steps that all scientific investigations follow. Different kinds of questions suggest different kinds of scientific investigations *(NSTA Position Statement, 2000)*
- For more information visit http://undsci.berkeley.edu/article/howscienceworks

NOSSE ER STRATEGY PROMPT
Practice: Describe the traditional scientific method that you are most familiar with and whether your view agrees with the standards (Tennessee, NGSS, and NSTA) and information above. Explain your reasoning.

NOS EXAMPLE PROMPT
Two teachers are asked whether they agree that to do good science all investigations must follow the scientific method or whether there are many scientific methods. Below are their responses. Which response better represents a view that is in agreement with the guide sheet above? (Tennessee, NGSS, and NSTA) Explain your reasoning.

(EXEMPLAR CARDS)

Teacher 1: "Scientists can follow different methods depending on what they want to answer. Sometimes they do experiments and sometimes they can only make observations. Both are science because they both are from the real world."	**Teacher 2**: "I think that scientists must follow the scientific method because it gives good data and good results. It is a good method to make sure that science is being done great and they can prove their answer. Otherwise it is just an opinion."

NOSSE GUIDE: EMPIRICAL

Guiding Question: To what extent is scientific knowledge based on and/or derived from observations of the natural world? In what sense is it not always empirically based? (Clough, 2007)

Saying scientific knowledge is empirically based means that scientific knowledge is based on or derived from observations of the natural world. Beliefs about a particular idea will not be accepted by the scientific community unless it is supported by empirical evidence (from observations or experiments).

Science Education Standards Documents: Empirical Nature of Scientific Knowledge Part 1

Next Generation Science Standards (p. 5, Appendix H)

Aspect of Scientific Knowledge	*K-2 Understandings*	*3-5 Understandings*	*Middle School Understandings*	*High School Understandings*
Scientific Knowledge is Based on Empirical Evidence	Scientists look for patterns and order when making observations about the world.	Science findings are based on recognizing patterns. Scientists use tools and technologies to make accurate measurements and observations.	Science knowledge is based upon logical and conceptual connections between evidence and explanations. Science disciplines share common rules of obtaining and evaluating empirical evidence.	Science knowledge is based on empirical evidence. Science disciplines share common rules of evidence used to evaluate explanations about natural systems. Science includes the process of coordinating patterns of evidence with current theory. Science arguments are strengthened by multiple lines of evidence supporting a single explanation.

<u>Science Education Standards Documents</u>: Empirical Nature of Scientific Knowledge Part 2

From Next Generation Science Standards (p. 6, Appendix H)

Aspect of Scientific Knowledge	*K-2 Understandings*	*3-5 Understandings*	*Middle School Understandings*	*High School Understandings*
Science Addresses Questions About the Natural and Material World	Scientists study the natural and material world.	Science findings are limited to what can be answered with empirical evidence.	Scientific knowledge is constrained by human capacity, technology, and materials. Science limits its explanations to systems that lend themselves to observation and empirical evidence. Science knowledge can describe consequences of actions but is not responsible for society's decisions.	Not all questions can be answered by science. Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions. Science knowledge indicates what can happen in natural systems—not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge. Many decisions are **not** made using science alone, but rely on social and cultural contexts to resolve issues.

NOSSE ER STRATEGY PROMPT

Think about the question, "What is science?" Reflect on what the science education standards documents say about "What is science?" Talk about this with your group. There are cards with examples of learning activities and investigations we have completed in class. Together, use BOB and your notes to select <u>at least 4</u> of the cards to place *on* the standards documents to show where the learning activity provided an example of the empirical nature of science. JUSTIFY your placement of each card in writing on a large sticky note.

NOS EXAMPLE STRATEGY PROMPT

When preservice elementary teachers are asked, “What is science?” they give many different responses. Reflect on what the NOSSE documents say about “What is science?” Talk about this with your group. Look at the cards with responses from elementary science teachers’ to the question, “What is science?” Determine which responses are most like, somewhat like, and least like these standards documents. Place the teacher response cards on the green line where you think they belong. JUSTIFY your placement in writing using a large sticky note. Choose 1 teacher response and match with an activity/investigation we have done in class that provides an example of the empirical nature of science. Use BOB and your notes.

EXEMPLAR CARDS

Teacher 1 Response:

Everything is science. You can’t get through a whole day without solving a problem or sitting there wondering about something; and you can do that in every single discipline.

Teacher 2 Response:

Science is a method of studying the natural world that uses systematic experimentation and/or observation to gain knowledge about events in nature.

Teacher 3 Response:

Science is the study of everything.

Teacher 4 Response:

Science can be tested and other things like religion are based off faith and not tested.

Teacher 5 Response:

Science depends on observation…but I think what we observe is a function of convention. I don’t believe that the goal of science is (or should be) the accumulation of observable facts.

NOSSE GUIDE: HUMAN ENDEAVOR(OBSERVATION/INFERENCE)

Guiding Question: How are observations and inferences different? In what sense can they not be differentiated? (Clough, 2007)

Observations differ from inferences and this distinction is important because scientific knowledge utilizes <u>both</u> observations and inferences. Scientific knowledge is inferential; observations are <u>interpreted</u> with theory. Inferences are statements about phenomena that are not directly accessible to the senses (atoms, genes/DNA, magnetic fields, etc…). For example, objects tend to fall to the ground because of gravity. The notion of gravity is inferential in the sense that it can be accessed and/or measured only through the manifestations or effects. Evidence is interpreted data.

<u>Science Education Standards Documents</u>: Science is a Human Endeavor

Aspect of Scientific Knowledge	*K-5 Understandings*		*Middle School Understandings*	*High School Understandings*
Science is a Human Endeavor	People have practiced science for a long time. Men and women of diverse backgrounds are scientists and engineers. Men and women from all cultures and backgrounds choose careers as scientists and engineers. Most scientists and engineers work in teams. Science affects everyday life. Creativity and imagination are important to science.	The scientific questions asked, the observations made, and the conclusions in science are to some extent influenced by the existing state of scientific knowledge, the social and cultural context of the researcher and the observer's experiences and expectations. * People may interpret the same results in different ways ** Results of an investigation are compared to what scientists already accept about this topic/question **	Men and women from different social, cultural, and ethnic backgrounds work as scientists and engineers. Scientists and engineers rely on human qualities such as persistence, precision, reasoning, logic, imagination, and creativity. Scientists and engineers are guided by habits of mind such as intellectual honesty, tolerance of ambiguity, skepticism and openness to new ideas. Advances in technology influence the progress of science and science has influenced the advances in technology.	Scientific knowledge is a result of human endeavor, imagination, and creativity. Individuals and teams from many nations and cultures have contributed to science and to advances in engineering. Scientists' backgrounds, theoretical commitments, and fields of endeavor influence the nature of their findings. Technological advances have influenced the progress of science and science has influenced advances in technology. Science and engineering are influenced by society and society is influenced by science and engineering.

Next Generation Science Standards (p. 5, Appendix H), NSTA Position Statement (*), TN Science Standards (**)

NOSSE ER STRATEGY PROMPT

Think about the question, "Can scientists know something without directly observing it (such as with dinosaurs)?" Reflect on what the NOSSE documents say about science as a human endeavor and the role of empirical evidence in science. Talk about this with your group. There are cards with examples of learning activities and investigations we have completed in class. Together, use BOB and your notes to select at least 3 of the cards to place *on* the standards documents to show where the learning activity provided an example how scientists can know without direct observation. Each person JUSTIFY your placement of each card in writing on a large sticky note.

NOS EXAMPLE STRATEGY PROMPT

When preservice elementary teachers are asked, "Can scientists know something even if they cannot directly observe it (such as with dinosaurs)?" they give many different responses. Reflect on what the science education standards documents say about how science is a human endeavor and the role of empirical evidence in science. Talk about this with your group. What activities/investigations completed in class can help us think about whether scientists can know something without directly observing it? Look at the cards with responses from elementary science teachers' & their students to the question. Determine which responses are most like, somewhat like, and least like these standards documents. Place the teacher response cards on the green line where you think they belong. JUSTIFY your placement in writing using a large sticky note (place next to teacher responses).

EXEMPLAR CARDS

Teacher 1 Response:
Scientist used the term dinosaurs to label a group of bones that appear to have several things in common. Although we do not have "real" evidence of their appearance, scientists are able to use technology to determine the age and make-up of the bones. The information gathered allowed scientist to infer and make the conclusion that they existed many years ago.

Teacher 2's Student Response:
People saw dinosaurs, and that is how scientists know about them.

Teacher 3 Response:
Unless a complete skeleton was found, their ideas are based on known factors (such as the skeletal structures of lizards). They put all bones together and created a dinosaur based on known factors, knowledge and not first-hand eyewitness testimonies.

Teacher 4 Response:
Scientists don't know for sure what dinosaurs looked like. I think that a lot of them have guessed to figure it out. I think they look at other animals that we have now, and they try to figure out if they had similar characteristics

Teacher 5 Response:
Science is something that is straightforward and isn't a field of study that allows for opinions, personal bias, or individual views-it is totally observation/fact based.

NOSSE GUIDE: SCIENTIFIC KNOWLEDGE IS TENTATIVE YET DURABLE
Guiding Question: In what sense is scientific knowledge tentative? In what sense is it durable? (Clough, 2007)

We know scientists no longer use the term "Monera" to describe a kingdom, though you might find this term in textbooks or online resources as you teach. This is an example of our next characteristic of scientific knowledge:

Scientific Knowledge is Open to Revision in Light of New Evidence

> *Scientific knowledge is tentative yet durable. Scientific knowledge is never 100% certain (cannot be proven) but the scientific community accepts scientific ideas that are supported by large amounts of scientific evidence until new information, discoveries, and technologies lead scientists to expand and refine scientific knowledge.*

Science Teaching Standards Documents Say:

- The only consistent characteristic of scientific knowledge across the disciplines is that scientific knowledge itself is open to revision in light of new evidence (NGSS, Appendix H)
- Scientific knowledge is simultaneously reliable and tentative. Having confidence in scientific knowledge is reasonable while realizing that such knowledge may be abandoned or modified in light of new evidence or reconceptualization of prior evidence and knowledge (NSTA position statement)
- Science knowledge can change when new information is found (NGSS, K-2, Understanding the Nature of Science)
- Most scientific knowledge is quite durable but is in principle, subject to change based on new evidence and/or reinterpretation of existing evidence (NGSS, High School)

NOSSE ER STRATEGY PROMPT

1. Do you think continuing to use the term "Monera" supports or does not support the standards listed above? Be sure to explain your reasoning.

2. What you will say to students you teach if they come across the term "Monera" in their textbook or online?

3. Explain in your own words how scientific knowledge is both tentative (open to revision in light of new evidence) yet durable (having confidence in scientific knowledge is reasonable). In your response, be sure to provide an example of scientific knowledge that is durable and why it is durable.

NOS EXAMPLE STRATEGY PROMPT

Explain in your own words how scientific knowledge is both tentative (open to revision in light of new evidence) yet durable (having confidence in scientific knowledge is reasonable). In your response, be sure to provide an example of scientific knowledge that is durable and why it is durable.

EXEMPLAR CARDS

Teachers were asked, "Do you think the knowledge scientists produce may change in the future?" Use the standards document information listed on the previous page to describe WHY each teacher's response was placed in the categories displayed below. Note, an expert on the characteristics of scientific knowledge placed the teacher responses on the chart. If you disagree with a placement then explain.

Example. Teacher 1's answer was less like the standards documents because…

LESS like standards documents

SOMEWHAT like standards documents

MORE like standards documents

Teacher 1
Scientific theories do not change. New information is often assimilated to fill in gaps, but scientific theories are basically well developed enough that they are widely accepted.

Teacher 4
I do think that there will be theories that we have today that may change in the future. In the future there will be so many technological advances that will be used to actually find out whether those theories are correct or not.

Teacher 5
Scientific theories frequently change. A theory is just our attempt to explain natural phenomena. A new observation or the results of a new experiment may reveal that the explanation doesn't "work" or fit the evidence, and scientists will alter or abandon the theory, or come up with different (but still plausible) theories to explain the event

Teacher 2
Scientists create new information, learn new information, and discover new information, which leads to the conclusion that all scientific knowledge is a starting point for new knowledge. Scientists are always expanding on old knowledge and building new knowledge.

Teacher 3
Yes, scientists are making new discoveries every day and what may have been thought of as true in the past become subject to debate and sometimes is even tossed out as factual…

NOSSE GUIDE: DATA IS DIFFERENT FROM EVIDENCE
Guiding Question: In what ways are data and evidence different? In what ways are they similar?

Science Practices: Analyzing & Interpreting Data

- **TN Science Standards, 3rd Grade:** *Recognize that people may interpret the same results in different ways.*
- **NGSS Appendix F, p. 23:** *Scientific investigations produce data that must be analyzed in order to derive meaning. Because data patterns and trends are not always obvious, scientists use a range of tools—including tabulation, graphical interpretation, visualization, and statistical analysis—to identify the significant features and patterns in the data.*
- **NGSS Science Practices, Grades 3-5:** *Analyze and interpret data to make sense of phenomena, using logical reasoning, mathematics, and/or computation.*
- **NGSS, Appendix F, p. 9:** *Once collected, data must be presented in a form that can reveal any patterns and relationships and that allows results to be communicated to others. Because raw data as such have little meaning, a major practice of scientists is to organize and interpret data through tabulating, graphing, or statistical analysis. Such analysis can bring out the meaning of data—and their relevance—so that they may be used as evidence.*

"…data and evidence are not the same… data are the information gathered during an investigation, but the interpretation of data as being supportive or contrary to a particular prediction or conclusion is evidence. In short, evidence is interpreted data.
-From Dr. Norm Lederman, **"What is Scientific Inquiry?"** http://msed.iit.edu/projectican/teachers1.html

NOSEE ER PROMPT (PEER INSTRUCTION CONCEPTEST FORMAT)
Based on science standards documents, which statement best describes the relationship between data and evidence?

Data is the same as evidence
Data is different from evidence
Data is somewhat the same as evidence

Two scientists have the same data and reach different conclusions. Explain why this occurs and how a third person might go about determining which scientist's claim has more evidence. Use the standards and information provided to support your response.

NOS EXAMPLE STRATEGY PROMPT (PEER INSTRUCTION CONCEPTEST FORMAT)

Based on the science standards documents, which teacher's view of the relationship between data and evidence is most like the standards?

> **Teacher A**: Data and evidence are same to me, just with different names. They're both information to back up or support a claim and are important in scientific investigations.
> **Teacher B**: Data is different from evidence. Data is something that you collected from your investigations but, everyone looks at the data from their point of view and they interpret it differently, so evidence is your perspective on an experiment that you use to support or prove a point.
> **Teacher C**: Data is somewhat different from evidence. We will have evidence after doing and investigation and evidence can prove that we are right. Data is just information that we can work with or check with our results.

Two scientists have the same data and reach different conclusions. Explain why this occurs and how a third person might go about determining which scientist's claim has more evidence. Use the standards and information provided above to support your response.

APPENDIX 3.D

Institutional Review Board Approval Letter

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research Compliance,
010A Sam Ingram Building,
2269 Middle Tennessee Blvd
Murfreesboro, TN 37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBN001 - EXPEDITED PROTOCOL APPROVAL NOTICE

Friday, July 29, 2016

Investigator(s): Jennifer Parrish (Student PI) and Grant Gardner (FA)
Investigator(s') Email(s): *jp4k@mtmail.mtsu.edu; grant.gardner@mtsu.edu*
Department: Biology/CBAS

Study Title: ***Developing pre-service elementary teachers' understandings of nature of science and science inquiry***
Protocol ID: **16-2315**

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU Institutional Review Board (IRB) through the **EXPEDITED** mechanism under 45 CFR 46.110 and 21 CFR 56.110 within the category *(7) Research on individual or group characteristics or behavior* A summary of the IRB action and other particulars in regard to this protocol application is tabulated as shown below:

IRB Action	APPROVED for one year from the date of this notification	
Date of expiration	**7/29/2016**	
Sample Size	50 (FIFTY)	
Participant Pool	**Adult preservice elementary teachers enrolled in at least two course sections of BIOL3000**	
Exceptions	NONE	
Restrictions	**Collection of signed informed consent is mandatory**	
Comments	NONE	
Amendments	**Date**	**Post-approval Amendments**
		NONE

This protocol can be continued for up to THREE years (**7/29/2019**) by obtaining a continuation approval prior to **7/29/2017**. Refer to the following schedule to plan your annual project reports and be aware that you may not receive a separate reminder to complete your continuing reviews. Failure in obtaining an approval for continuation will automatically result in cancellation of this protocol. Moreover, the completion of this study MUST be notified to the Office of Compliance by filing a final report in order to close-out the protocol.

Continuing Review Schedule:

Reporting Period	Requisition Deadline	IRB Comments
First year report	6/29/2017	INCOMPLETE
Second year report	6/29/2018	INCOMPLETE
Final report	6/29/2019	INCOMPLETE

CHAPTER FOUR: USING STUDENTS' EXEMPLAR RESPONSES FROM NOS SURVEY INSTRUMENTS TO PROMOTE IN-SERVICE BIOLOGY TEACHERS' REFLECTION ON NATURE OF SCIENCE AND SCIENTIFIC INQUIRY

Introduction

Developing K-12 science teachers' understandings of scientific inquiry (SI) and nature of science (NOS) continues to be a major goal of K-12 science education reform (e.g., American Association for the Advancement of Science [AAAS] 1990, 1993; National Research Council [NRC] 1996, 2000, 2011; NGSS Lead States, 2013). In the context of K-12 science education, nature of science (NOS) refers to the *characteristics* of scientific knowledge while scientific inquiry (SI) refers to the *process* scientists use to generate scientific knowledge (Bartos, 2014; Lederman, 2007). The goals outlined in science reform documents, such as the Next Generation Science Standards (NGSS), state that teachers should include NOS and SI in their instructional practice to develop students' understandings of these constructs, with the overarching goal of developing scientifically literate citizens (Driver et al., 1996; NRC, 2012). Indeed, arguments have been made that SI and NOS should be planned for, included, and assessed in K-12 science classrooms in the same manner as traditional science content (Lederman, 2006). However, teachers continue to struggle to develop adequate NOS and SI Pedagogical Content Knowledge (PCK) to enable them to explicitly include NOS and SI in classroom instruction (Akerson, Pongsanon, Park Rogers, Carter, & Galindo, 2017; Wahbeh & Abd-

El-Khalick, 2014). As such, students continue to hold understandings of NOS and SI incongruent with science reform recommendations (Lederman & Lederman, 2014).

Teacher's NOS and SI Understandings

Teachers must possess adequate conceptions of both NOS and SI to begin to be able to transfer this knowledge into their classroom practices (Abd-El-Khalick & Lederman, 2000; Shulman, 1986; 1987). Although a variety of approaches have been used to improve teachers' conceptions of NOS (e.g., McComas, 1998), a large body of evidence supports that using explicit and reflective (ER) strategies in the context of a variety of teacher professional development settings is an effective means to improve inservice teachers' NOS and SI conceptions (Bloom, Binns, & Koehler, 2015; Donnelly & Argyle, 2011; Lotter, Singer, Godley, 2009; Wahbeh & Abd-El-Khalick, 2014; White, 2010). In general, ER strategies used in professional development include instructor questioning or group discussions to make targeted aspects of NOS and SI explicit and visible (Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001). It is essential that NOS and SI are made explicit and time is provided for teacher-learners to reflect on NOS or SI to effectively change their conceptions (Lederman & Abd-El-Khalick, 1998).

A common misconception among educators is that understandings of SI and NOS can be developed implicitly simply by engaging in the practices of science (Abd-El-Khalick & Lederman, 2000; Lederman, N., Bartos, S, & Lederman, J. 2014; Metz, 2004). Teachers have come to believe that if they simply incorporate inquiry activities into their instruction, students will develop adequate understandings of NOS and SI. However, this is simply not the case according to decades of research (Abd-El-Khalick & Lederman, 2000). The following analogy provided by Lederman and Abd-El-Khalick (1998) makes clear the need to make NOS and SI explicit:

> "…teachers have been led to believe that their students will come to understand the NOS simply through the performance of scientific inquiry and/or investigations. This advice is no more valid than assuming that students will learn the details of cellular respiration by watching an animal breathe…" (p. 83).

Assessing NOS and SI Understandings

Science education researchers often use general aspect lists to assist in defining, teaching, and assessing K-12 teacher and student views of NOS and SI (Kampourakis, 2016). In many instances, these lists have been central to the iterative development of various assessment instruments used to measure SI and NOS understandings in K-12 education settings (see Abd-El-Khalick, 2014, p.624-625). Examples of such assessment tools include the Views of Scientific Inquiry (VOSI) (Schwartz, Lederman, & Lederman, 2008) and the Views of Nature of Science (VNOS) (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) questionnaires. These open-ended, short answer questionnaires gauge how individuals perceive and understand processes in science responsible for generating and justifying scientific knowledge (SI) and aspects regarding the nature of this knowledge (NOS).

Collectively, the VNOS and VOSI surveys are the most extensively used NOS and SI assessment tools in K-12 education and teacher professional development settings (see Chapter 2). It should be noted that these questionnaires aim to measure understandings of general aspects of SI and NOS (Table 4.1) that are not new or controversial (Abd-El-Khalick, 2012) and are appropriate for use with both teachers and students in K-12 educational settings (Lederman & Lederman, 2014; Smith, Lederman, Bell, McComas, & Clough, 1997).

Table 4.1

Some Aspects of NOS and SI

NOS	**SI**
Scientific knowledge…	When generating scientific knowledge…
• Is empirical and based on or derived from observations of the natural world	• Investigations begin with and are guided by the scientific questions asked
• Is tentative, yet durable until new information leads scientists to expand and refine knowledge*	• There is no single set or sequence of steps in a scientific investigation (no one scientific method)*
• Is subjective.	• Data are not the same as evidence*
• Is a product of human imagination and creativity*	• Scientific explanations are developed using evidence and what is already known.
• Is affected by the society and culture in which it is developed.	• Research conclusions must be consistent with data
• Includes theories & laws, which are distinct types of knowledge	• Scientists work in a community of practice
• Uses both observations and inferences*	• Scientists following the same procedures will not necessarily arrive at the same results

Note. This is not an exhaustive aspect list and others exist. See Osborne et al., (2003); Alshamrani (2008); among others. The focus of the current study was on aspects indicated by an *

Multiple versions of the VNOS and VOSI questionnaires are available, each tailored for a specific audience (Table 4.2). Recently, the Views About Scientific Inquiry (VASI) (Lederman et al., 2014) was developed to better assess views of SI as outlined in NGSS. These instruments have been validated with a wide variety of audiences in multiple contexts and generally take respondents less than an hour to complete (Lederman, Bartos, & Lederman, 2014). In addition, the short answer response format does not restrict respondents' views, and follow-up interviews enable researchers to develop a rich profile that reflects what a participant thinks about scientific knowledge. The aforementioned reasons may explain the extensive use of these instruments in research studies.

Table 4.2

Assessment Instruments for Evaluating Participant NOS and SI Conceptions

Target Audience	Form
Scientists	VOSI-Sci
Inservice & Preservice Teachers	VOSI-270, E
High School Students	VOSI 1, 4, Sec; VASI
Middle School Students	VOSI-M, E, 2, 3; VASI
Elementary Students	VOSI-E
Vary by length and targeted aspects	VNOS-A, B, C, D, E

Note. See Schwartz, Lederman, & Lederman (2008), Lederman, Abd-El-Khalick, Bell, & Schwartz (2002), and Lederman et al., (2014).

Teacher Professional Growth for NOS and SI

The VNOS, VOSI, and VASI surveys have provided a plethora of evidence to support a need to continue to examine how inservice science teachers can grow professionally to better understand NOS and SI (Lederman & Lederman, 2014). Numerous models have been developed to gauge the success of teacher professional development endeavors (eg., Guskey, 1986), but a major criticism has been that these models are over-simplified and unable to explain the complex processes involved in teachers' professional growth (Avalos, 2011). One model that accounts for the multi-faceted components of teacher development is Clarke and Hollingsworth's (2002) Interconnected Model for Teacher Professional Growth (IMTPG). This model assumes teacher change is a complex, non-linear process and organizes factors thought to influence teacher professional growth into four discrete categories, referred to as change domains (Figure 4.1).

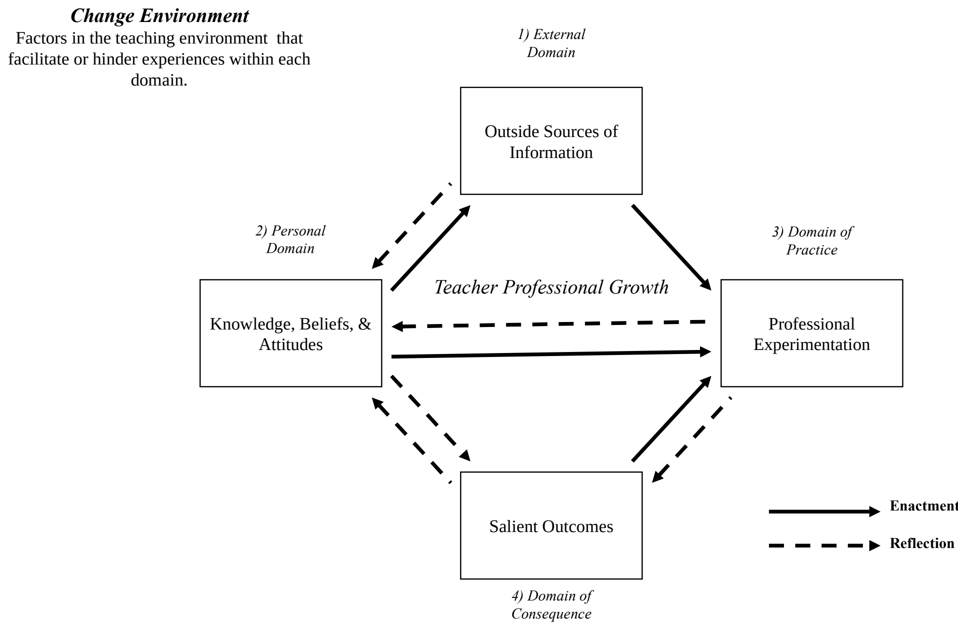

Figure 4.1. Interconnected Model of Teacher Professional Growth (Study 2). The personal domain includes any characteristic of the instructor that they bring with them into their practice, such as personal beliefs, attitudes, and content knowledge related to instruction. The domain of practice includes the pedagogical decisions and approaches used by the teacher. The domain of consequence consists of the salient outcomes desired by the teacher from their students, such as student understanding, behavior, or motivation (among others). The external domain includes any external stimuli outside the boundaries of the teaching environment that influence events that occur inside the classroom. All change domains reside in the larger *change environment*, which encompasses any facet that potentially encourages or constrains a teacher's professional growth (e.g., school community, administration, cultural norms, etc.).

Change Mechanisms

Two key change mechanisms mediate change among IMTPG domains are reflection and enactment. Enactment goes beyond typical teacher actions, and is a change mechanism that occurs when a teacher acts as a result of newly acquired information. Reflection, the second change mechanism and focus of this manuscript, is defined in the IMTPG per Dewey (1910) as “active, persistent, and careful consideration” (p. 4) of existing beliefs (about NOS and SI) with reference to new information. Reflection has been identified as a key process needed to facilitate changes in teaching and learning at all levels (Hatton & Smith, 1995; Henderson, Beach, & Finklestein, 2011; Schon, 1983; Ward & McCotter, 2004). As this mechanism is a key component of ER NOS approaches, reflection is the focus of this study.

Teacher growth can be analyzed using the IMTPG framework by identifying sequences of changes between domains (e.g., external to personal) or more extensive sequential changes among multiple domains (e.g., external to practice, to personal). Clarke and Hollingsworth (2002) describe changes that are observed once as change sequences, while changes that persist over time are identified as growth networks. In the current study the researcher attempted to use multiple data sources to identify any change sequences that occurred as a result of teacher participation in a novel, researcher-created ER NOS strategy.

Study Goals and Rationale

Research Question

A variety of evidence-based ER NOS approaches have been used to improve teachers’ NOS and/or SI conceptions, and in some cases, teaching practices (See Chapter 2). However, even teachers who engage in sustained, long-term ER NOS and SI instruction can tenaciously hold on to naïve conceptions (Akerson, Buzzelli, & Donnelly, 2008; Clough, 2006). The goal of the current study was to develop and examine a novel

ER NOS/SI approach called the Nature of Science for Science Education (NOSSE) Exemplar Strategy which uses students' exemplar responses on the VNOS, VOSI, and VASI to explicitly draw teachers' attention to the aspects of SI and NOS through students' thinking (domain of consequence), while potentially promoting reflection to change teachers' understandings of SI and NOS (personal domain). See Figure 4.2. The study aimed to answer the following research question:

> How and to what extent does using students' exemplar responses from the VNOS and VOSI surveys promote teacher reflection and professional growth for NOS and SI, if at all?

The following section will describe the rationale for and development of the NOSSE Exemplar Strategy as the intervention for this study.

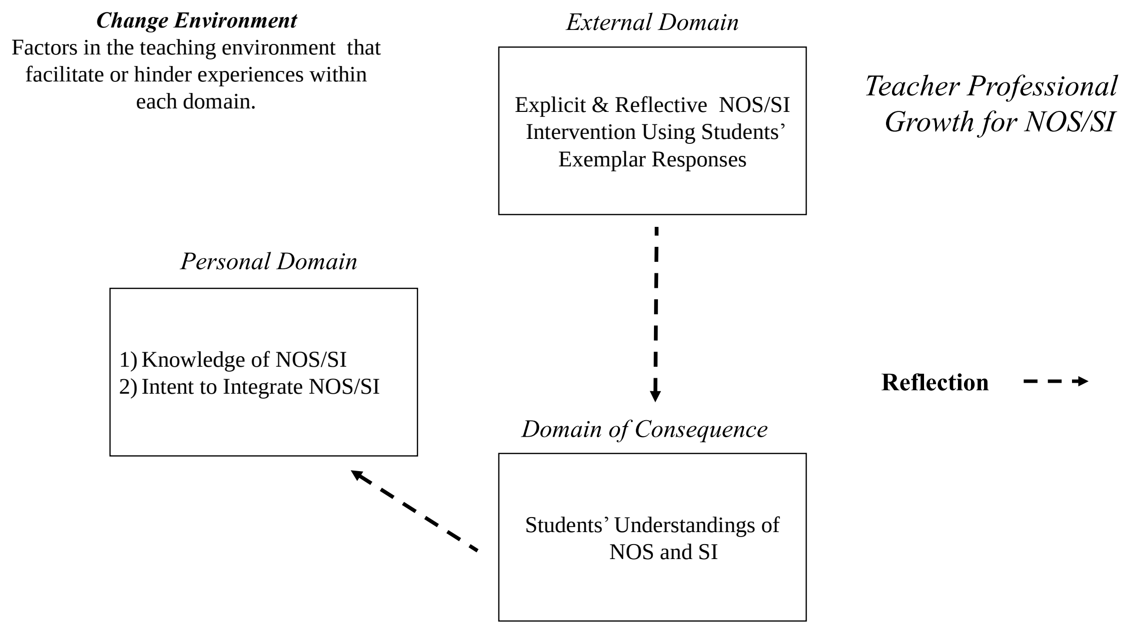

Figure 4.2. Study focus on changes in the IMTPG domain of consequence and personal domain via reflection as a result of engaging in the NOSSE Exemplar Strategy.

NOSSE Exemplar Intervention

The NOSSE Exemplar Strategy was developed and examined with two inservice high school biology teachers. The strategy consisted of two parts. First, teachers were provided with researcher-created Nature of Science for Science Education (NOSSE) Guides, each with general information about a particular NOS or SI aspect (Appendix 4.A). The NOSSE Guides provided each teacher with an explicit introduction to expert-like views of NOS aspects. Second, each teachers' students were given modified versions of the VNOS, VOSI, and VASI surveys to generate exemplar student responses for each teacher to examine and compare to the NOSSE Guide. I will next describe the rationale for the strategy and how it was used as a means to promote teacher professional growth for NOS and SI conceptions in this study.

Learning by Ostention

The NOSSE Exemplar Strategy was designed based on the idea of concept learning, also called ostention (Kuhn, 1974) where learners examine and categorize exemplars to refine their understanding of a particular concept (Andersen, 2000; Schwartz & Bransford, 1998). Using examples in this manner to develop mental representations of concepts through rules, prototypes, or exemplars is not a new approach to teaching and learning (Bruner, Goodnow, & Austin, 1956; Schwartz & Bransford, 1998; Kahn & Zeidler, 2016). In fact, strategies based on ostention have been used with some success to develop teachers' NOS conceptions. For example, in a study by Smith & Scharmann (2008), preservice teachers were asked to examine paired terms or statements and decide whether each was more or less scientific. Through small group and whole-class discussions, teacher-learners had to reflect on two terms (e.g., biology/ religion, or intelligent design/reincarnation, among others) and come to a consensus about which term was more scientific based on specific criteria. Teacher-learners who engaged in this strategy showed professional growth in their understandings of NOS, as they were able to identify the theory of evolution as scientific and intelligent design theory as not scientific, despite being enrolled at a conservative, religious institution.

Craven, Hand, and Prain (2002) also used principles of ostention to help preservice teachers delineate between science and pseudoscience. Teacher-learners were asked to identify examples of writing in newspaper or journal articles that exemplified pseudoscience and science, then describe the characteristics of each type of writing. In this study, comparing writing exemplars promoted reflection on the nature of scientific knowledge through argumentation and deliberation (Rodgers, 2002). Collectively, these studies show how principles of ostention have been used to facilitate teacher professional growth for NOS.

Reflective Exemplars

The NOSSE Exemplar Strategy was based on similar ostensive principles. The genesis for the idea resulted after conducting a pilot study in which the VASI was used to measure 5th grade students' understandings of inquiry (Parrish, Bartos, Sadler, & Gardner, in progress). Originally, the study was intended to examine changes in students' inquiry understandings after completing an open-inquiry unit while receiving ER SI instruction. Results showed that students' understandings shifted away from sophisticated views for some aspects of SI. This was contrary to what was expected. An impromptu meeting between the researcher and this 5th grade teacher to discuss the VASI results resulted in the teacher asking to see exemplar student responses and overall trends from her students' data.

Unexpectedly, this teacher reflected on her students' contrasting naïve and informed exemplar responses and noted two things. First, she described how breaking SI into aspects (something she had never been introduced to in over twenty years as a science educator) helped her think about understanding scientific inquiry (SI) as different from using inquiry as a pedagogical approach (e.g., engaging students using science activities). She reflected on her own understandings of SI by comparing students' exemplar responses with her own conceptions. This resulted in her thinking how she could help her students to think critically about specific aspects of SI *as* they engaged in inquiry projects, with the overall goal of having her students develop more sophisticated SI understandings. Second, she described how she could be more explicit and address the misconceptions her students held regarding certain aspects of SI. In this case, the VASI student data and exemplar responses were used as a reflective tool that enabled a teacher to reexamine her approach to inquiry teaching. Reflection spurred changes between IMTPG domains, resulting in teacher professional growth for SI (Figure 4.3).

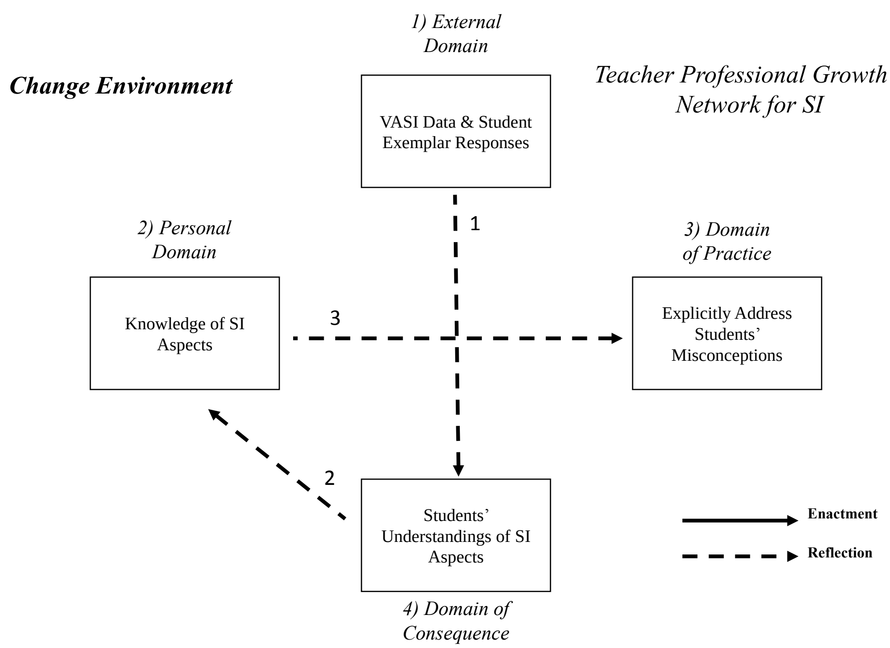

Figure 4.3. Teacher change sequence for SI observed when VASI data and exemplar responses were used as a reflective tool. Reflective link 1 indicates that students' exemplar responses (external domain) caused changes regarding teachers' understandings of her students' misconceptions (domain of consequence) about SI. Reflective link 2 indicates that awareness of students' misconceptions about SI caused changes in teachers' understanding about specific aspects of SI (personal domain). Reflective link 3 indicates these changes resulted in intentions to explicitly address students' misconceptions about SI aspects in classroom practice (domain of practice). Data sources for reflective links included teacher interviews and classroom observations.

The NOS and SI literature is replete with examples of student and teacher responses to the VNOS, VOSI, and VASI questionnaires, but based on my work with K-

12 teachers, rarely (if ever) do they report seeing this information. What seemed most powerful in the pilot study was the teacher accessing and reflecting on exemplar responses, specifically authentic exemplars from *her* students.

The first step in creating the NOSSE Exemplar Strategy for this particular study was to administer abridged versions of the VNOS, VOSI, or VASI questionnaires to each participating teachers' (n = 2) students. These surveys were scored by the researcher and were used to generate overall trends of students' understandings (e.g., percentage of students with naïve views) and compile exemplar student responses that represented views of NOS and SI aspects. Representative responses, those that clearly exemplified naïve or informed responses, or were thought provoking, were selected and printed on cards for the teacher participants. These cards and visual representations of overall trends in students' understandings were then used by teachers in the task described in the following section.

Development of Explicit NOSSE Guides

The NOSSE Example Strategy was created to assist inservice teachers with varying background knowledge, including teachers completely unfamiliar with NOS and SI ideas. Each NOSSE Guide was developed around a guiding question so the guide would assist teachers in exploring, not memorizing, NOS aspects (Clough, 2007). K-12 standards documents, position statements on NOS and SI, and relevant research literature in teacher education were reviewed to find information about each NOS aspect (Table 4.3). This information was compiled to create one-page NOSSE Guides, each which explained a particular NOS aspect in a manner congruent with K-12 science reform recommendations and was constructed to provide a clear description of a particular NOS and SI aspect representative of an “expert-like” view (Figure 4.4). All NOSSE Guides created by the researcher for this dissertation are included in Appendix 4.A.

Table 4.3

Resources Used to Construct NOSSE Guides

Type	Source
Teacher Association Position Statements	NSTA Position Statement on NOS, 2000, retrieved from http://www.nsta.org/about/positions/natureofscience.aspx
Publications for Teaching NOS	National Academy Press (1998). *Teaching about evolution and the nature of science*. Washington: DC.
NOS Articles	McComas, W.F. (1996). Ten myths of science: Reexamining what we think we know about the nature of science. *School Science and Mathematics, 96*(1), 10-16. McComas, W.F. (2004). Keys to teaching the nature of science: Focusing on the nature of science in the science classroom. *The Science Teacher, 71*(9), 24-27. Lederman, J. S., Lederman, N. G., Bartos, S. A., Bartels, S. L., Antink Meyer, A., & Schwartz, R. S. (2014). Meaningful assessment of learners' understandings about scientific inquiry- The views about scientific inquiry (VASI) questionnaire. *Journal of Research in Science Teaching, 51*(1), 65-83. Clough, M. P. (2007). Teaching the nature of science to secondary and post-secondary students: Questions rather than tenets. *The Pantaneto Forum*, 25, retrieved from http://www.pantaneto.co.uk/issue25/clough.htm. Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching, 39*, 497-521. Osborne, J., Collins, S., Ratcliffe, M., Millar, R., & Duschl, R. (2003). What "ideas –about-science" should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching, 40*, 692-720.
Online NOS Resources	Project Inquiry, Context, and Nature of Science (ICAN) https://science.iit.edu/mathematics-science-education/resources/lederman-depository/what-nature-science How Science Works Retrieved from http://undsci.berkeley.edu/article/howscienceworks_01

For the current study, NOSSE Guides were often based on information contained in the NGSS document (Appendix H) and the state science standards where the study was conducted because these documents were already being used by teachers to guide their scope and sequence. Not all suggested NOS aspects are adequately described in national and state science standards documents, specifically NGSS (McComas & Nouri, 2016). Therefore, to fill in gaps to construct NOSSE Guides for aspects not included or well represented in standards documents, the NSTA position statement on NOS (2000), excerpts from *Teaching About Evolution and Nature of Science* (National Academy Press, 1998), and other resources written for the teaching and learning of NOS in K-12 settings (e.g., *Keys to Teaching the Nature of Science*, NSTA Press) were used.

Nature of Science for Science Education GUIDE
NOS Subdomain: Scientific Knowledge is Tentative, Durable, & Self-Correcting

Guiding Question: In what sense is scientific knowledge tentative? In what sense is it durable?[7]

Summary: Scientific knowledge is never absolute or certain. This knowledge, including "facts," theories, and laws, is tentative and subject to change. Scientific knowledge is never 100% certain (cannot be proven) **but** scientific ideas that are supported by large amounts of evidence are accepted by the scientific community until new information, discoveries, and technologies lead scientists to change, expand, and/or refine scientific knowledge. Scientific claims change as new evidence, made possible through advances in theory and technology, is examined in the context of existing theories or laws, or as old evidence is reinterpreted in the light of new theoretical advances or shifts in the directions of established research programs.[1] We can have confidence that scientific conclusions formed using the inquiry process will be long lasting or durable because of the rigorous, self-correcting nature of the scientific process and the requirement that conclusions are agreed to by the scientific community.[2]

What do science standards documents say about this NOS subdomain?

Next Generation Science Standards
Scientific Knowledge is Open to Revision in Light of New Evidence
- Most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.
- Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation.
- Science knowledge has a history that includes the refinement of, and changes to, theories, ideas, and beliefs over time.
- The certainty and durability of science findings varies.

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
- A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that has been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.

National Science Teachers Association NOS Position Statement
- Scientific knowledge is simultaneously reliable and tentative. Having confidence in scientific knowledge is reasonable while realizing that such knowledge may be abandoned or modified in light of new evidence or reconceptualization of prior evidence and knowledge.
- The history of science reveals both evolutionary and revolutionary changes. With new evidence and interpretation, old ideas are replaced or supplemented by newer ones.

What have nature of science experts said about this subdomain?

Teaching About Evolution and the Nature of Science:

"We talk about 'believing' in evolution, but that's not necessarily the right word. We accept evolution as the best scientific explanation for a lot of observations about fossils and biochemistry and evolutionary changes we can actually see, like how bacteria become resistant to certain medicines. That's why people accepted the idea that the earth goes around the sun because it accounted for many different observations that we make. In science, when a better explanation comes around, it replaces earlier ones. "Does that mean that evolution will be replaced by a better theory some day?" asks Karen. "It's not likely. Not all old theories are replaced, and evolution has been tested and has a lot of evidence to support it. The point is that doing science requires being willing to refine our theories to be consistent with new information."[4]

Sources: [1]Project ICAN https://science.iit.edu/mathematics-science-education/resources/lederman-depository/what-nature-science; [2]*Keys to Teaching NOS* McComas, 2004; [3]Lederman et al. 2002, and [4]*Teaching About Evolution and the Nature of Science* 1998; [5]NGSS Lead States, 2013; [6]NSTA Position Statement on NOS, 2000, http://www.nsta.org/about/positions/natureofscience.aspx [7]Questions rather than tenets, Clough, 2007

Figure 4.4. NOSSE Guide for the idea that scientific knowledge is tentative, durable, & self-correcting.

An Explicit Reflective Strategy

In the current study, each teacher worked one-on-one with the researcher during independent professional development sessions. The NOSSE Exemplar Strategy uses NOSSE Guides in conjunction with students' exemplar responses to provide teachers with an opportunity to reflect on their own NOS and SI understandings. The first step in the strategy was to provide the teacher with a NOSSE Guide to examine and have them describe in their own words the view of NOS presented therein. This was a time for the teacher to grapple with new ideas about the nature of scientific knowledge and become familiar with the information in the NOSSE Guide. Next, the teacher was provided with a continuum line (Figure 4.5) and 3-5 cards with exemplar responses. The teacher was then instructed to place their students' exemplar responses along the continuum according to whether their students' thinking was "more like" the information presented in the NOSSE Guide or "less like" the information presented. The NOSSE guide was used as a referent for the teacher to place the exemplar according to an expert-like view. Having teachers "carefully consider" (Dewey, 1910, p. 6) their students' thinking to place the response along the continuum provided an opportunity for reflection through deliberation (Rodgers, 2002; Dewey, 1910). An example of exemplar cards placed along the continuum by a teacher to target the tentative yet durable NOS aspect is provided in Figure 4.5.

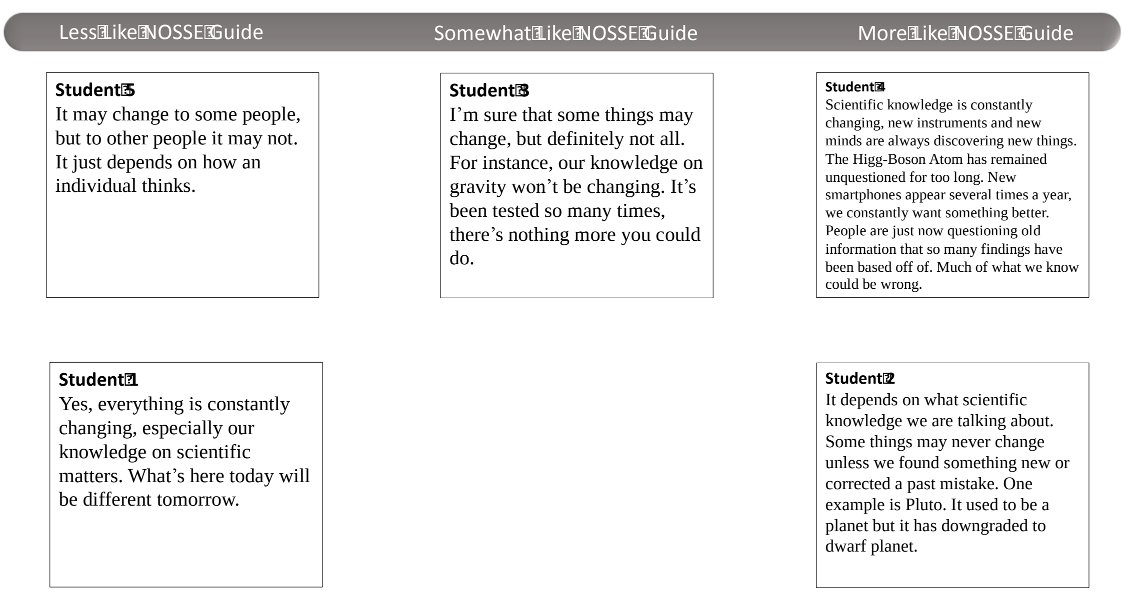

Figure 4.5. A participating teachers' placement of her high school students' VNOS exemplar cards.

The NOSSE Exemplar Strategy examined in this dissertation targeted the following five aspects of NOS or SI: 1) there is no single set or sequence of steps in a scientific investigation (no one scientific method), 2) scientific knowledge is tentative, yet durable until new information leads scientists to expand and refine knowledge, tentative, yet durable and self-correcting; 3) observations differ from inferences and science is a product of human imagination and creativity; 4) scientific investigations begin with and are guided by the scientific questions asked, and 5) data is different from evidence (Table 4.1).

Methods

Study Design

An exploratory case study design (Yin, 2014) was utilized to attempt to determine how and to what extent two in-service science teachers' reflection on SI and NOS was promoted by using the NOSSE Exemplar Strategy. A case study methodology was chosen in order to examine detailed participant thinking and justification while completing the NOSSE Exemplar Strategy intervention.

Case study participants were solicited via email from a group of 17 in-service biology teachers in the Southeastern United States who previously engaged in a year-long professional development program on which the author was a research assistant (NSF DRL-1417735). Teachers in this program were coached on using Peer Instruction ConcepTests as an active learning strategy (Mazur, 1997). To be selected for the current study, a teacher must have been scheduled to teach at least one section of a biology course for middle or high school students during both the fall 2016 or spring 2017 semesters, have at least five years of experience teaching biology at that grade level, actively engage students in constructivist learning, and agree to allow the researcher to be a part of their classroom, including interacting with students and conducting classroom observations over the course of the 2016 - 2017 school year. Early-career teachers are often overwhelmed by classroom management issues and lack of classroom teaching experience, making it difficult for them to incorporate ideas about NOS into their teaching (Gess-Newsome & Lederman, 1993; Lederman, 1999). Therefore, only teachers with at least five years of classroom experience were considered for this study.

Each teacher met individually with the researcher a total of five times to complete the NOSSE Exemplar Strategy (Table 4.5). These meetings occurred over the course of three months during the 2016 - 2017 school year. Each meeting addressed one or two NOS or SI aspects and lasted, on average, 30 minutes. Meetings took place during the teacher's planning period or after school.

Table 4.5

Aspects of NOS and SI Addressed at Each Meeting

Meeting	NOSSE Exemplar Strategy Aspect	Aspect Abbreviation
1	There is no single set or sequence of steps in a scientific investigation (no one scientific method).	MM
2	Scientific knowledge is tentative, yet durable until new information leads scientists to expand and refine knowledge.	TYD
3	Observations differ from inferences/ Science is a product of human imagination and creativity	OI/C
4	Scientific investigations begin with and are guided by the scientific questions asked.	SIBQ*
5	Data is different from evidence	DE

Note. *SIBQ was included in the NOSSE Exemplar Strategy (per teacher request) but not assessed on the VNOS or VOSI questionnaires.

Description of Participants

Two high school biology teachers (both female) met the criteria described above and agreed to participate in the study. Both teachers had 11 years of teaching experience and had Master's degrees in education. Participants were assigned the pseudonyms of Diane and Tracy.

Diane taught in a large, suburban school district in a high school with approximately 1,300 students. Diane's class sizes ranged from 28-32 and her teaching responsibilities included teaching two course sections of anatomy and physiology and two course sections of general biology. Diane's teaching style was typically didactic, and her students were always well-behaved and engaged, as evidenced by their questions. Diane loved to bring in personal stories from her experience in the medical field to exemplify key biology concepts and after each class period students would stay to ask additional questions.

The second teacher participant, Tracy, taught in a large, urban school district in a high school with approximately 2,300 students. Tracy's class sizes ranged from 18-26 and her teaching responsibilities included teaching six sections of honors level introductory biology. Tracy's teaching typically included student-centered, whole-class discussions with Tracy answering students' questions with questions.

Data Collection and Sources

To determine how and to what extent the NOSSE Exemplar Strategy promoted reflection and professional growth for NOS and SI, multiple data sources were used to identify factors within each IMTPG domain and the change environment predicted to be relevant to developing understandings and teaching practices for NOS and SI (Figure 4.6). Variables in the change environment of interest were teacher agency as measured by self-efficacy and beliefs about teaching science. Variables of interest within the personal domain were changes in teachers' conceptions of NOS and SI and intentions to integrate NOS in classroom practice after engaging in the NOSSE Exemplar Strategy. Students' conceptions of NOS and SI (domain of consequence) were also included, as was whether reflection (a mechanism for change) occurred while teachers completed the strategy.

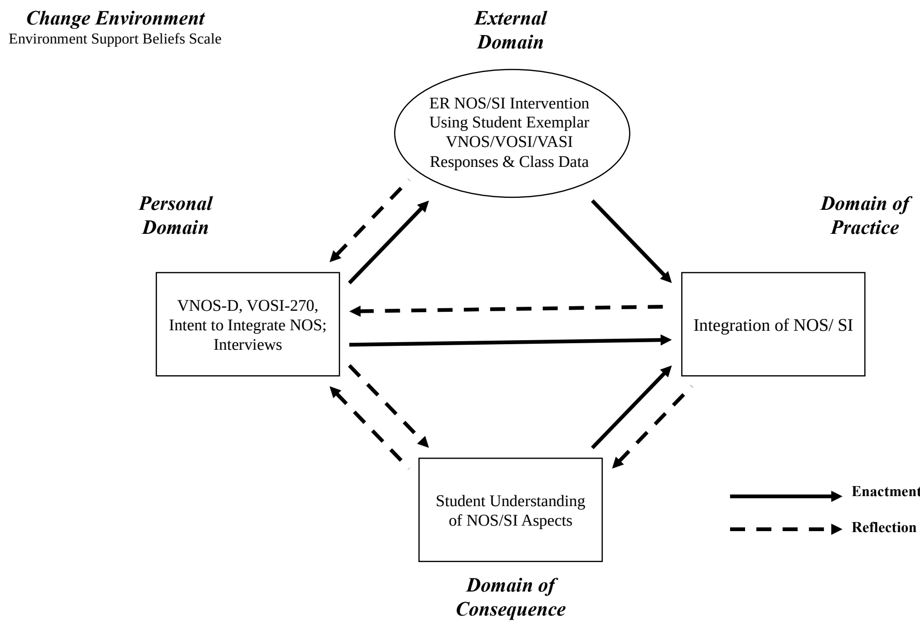

Figure 4.6. Data sources used to provide evidence for each teachers' rich profile regarding SI and NOS prior to engaging in the NOSSE Exemplar Strategy.

The Change Environment

Teacher professional growth for NOS and SI is a complex process (Lederman and Lederman, 2014; Wahbeh & Abd-El-Khalick, 2014) and is influenced by the interaction of many contextual factors within the teaching and learning environment (Opfer & Pedder, 2011). A change environment that is supportive of teachers' attempts to try innovative approaches may facilitate the degree to which teachers are able to reflect and change (Clarke & Hollingsworth, 2002). To determine change environment characteristics, each teacher was interviewed and asked to provide information about whether they felt supported by colleagues, administration, and parents. These interviews were audio recorded and transcribed.

Also, prior to the study, each teacher completed STEBI-B (Enochs & Riggs, 1995) and the Personal Agency Beliefs assessment based on a conceptual framework by Lumpe, Czerniak, Handy, and Beltyukova (2000) to determine teacher agency.

Personal Domain

NOS and SI conceptions. Prior to engaging in the NOSSE Exemplar Strategy (external domain) and again at the conclusion of the study, participants completed the VNOS (Version D) and VOSI (Version 270). Each teacher completed a follow-up interview to ensure written responses accurately represented their views. Interviews were recorded and transcribed. Participants' pre-and post-responses were coded as naïve, mixed, or informed for NOS and SI aspects, as typical of this analysis (Lederman et al., 2002). Responses were coded as *informed* if the response was congruent with accepted definitions or conceptions of NOS and SI found in standards documents. *Naïve* responses reflected misconceptions or a lack of understanding, while a *mixed* response was partially correct or contradicted other responses. Surveys were scored independently by two raters with experience scoring the VNOS and VOSI questionnaires. Initial interrater reliability was 90% for the VNOS-D and 93% for the VOSI-270, and all scoring discrepancies were resolved by further discussion and reevaluation until 100% agreement was reached for each participant.

Intent to integrate NOS. Each teacher completed the Intention to Integrate Nature of Science Questionnaire (Akyol, Oztekin, Sungur, & Abd-El-Khalick, 2016) pre and post intervention. This instrument measured changes in latent variables that may explain a teacher's intentions to integrate NOS into their classroom instruction. The questionnaire consisted of 52 Likert-type items based on an exploratory factor analysis, 12 items that did not intercorrelate with the hypothesized constructs were removed from the analysis (see Chapter 3, Appendix 3.A). Once removed, 7 factors were identified as reliable and included in this study: 1) teachers' readiness to integrate NOS into classroom instruction, 2) teachers' perception of the utility of NOS knowledge for students, 3) the pressure teachers perceive to integrate NOS, 4) teachers' beliefs about factors they can control regarding NOS integration, 5) teachers' perceived important outcomes for NOS instruction, 6) teachers' beliefs about normative expectations to integrate NOS, and 7) teachers' overall attitudes about integrating NOS.

Domain of Practice

At least two classroom observations were conducted in each participant's classroom prior to starting the study to enable the researcher to establish a rapport with each teacher and gauge typical pedagogical approaches. These observations were exploratory and did not rely on an observation protocol. They were used to identify context-specific biology lessons that could be used as examples to include in the NOSSE Exemplar Strategy discussions about how to make NOS and SI aspect explicit in lessons (Lederman & Lederman, 2004) and to determine whether teachers were currently including any explicit NOS or SI instruction.

Domain of Consequence

Within the first month of the study, students in each teacher's classroom completed an abridged version of the VNOS, VOSI, and VASI questionnaires (Appendix C) consisting of eleven open-ended questions. Both teachers selected were IRB certified and therefore able to administer the surveys to their students. Student responses were scored by the researcher as naïve, mixed, or informed (see above) and compiled to identify exemplar responses to be used in the NOSSE Exemplar Strategy and create graphs to show overall trends in student data.

Reflection

To determine whether the NOSSE Exemplar Strategy promoted teacher reflection, teachers were audio recorded while they completed the strategy with the researcher during independent professional development sessions. Participants were asked to think aloud and describe their reasoning as they placed student exemplar cards along the continuum. The discourse between the researcher and the teacher was transcribed and coded for instances of reflection using a coding scheme (Table 4.6) developed primarily from the elements of reflection identified by Akbari, Behzadpoor, & Dadvand (2010), Schon (1983), and Dewey (1910). Rodgers' (2002, p. 845) extension of Dewey's work which identified four criteria of reflection was also used: 1) reflection is a meaning-making process that promotes deeper understanding, 2) reflection is a systematic and rigorous way of thinking, 3) reflection must occur with others, and 4) reflection requires the reflector to value personal and intellectual growth. Once instances of reflection were coded they were used to determine specific change sequences that occurred as a result of the NOSSE Exemplar Strategy. These change sequences were visualized using IMTPG diagrams (see Clarke & Hollingsworth, 2002) for each aspect of NOS and SI.

Table 4.6

Coding Scheme to Identify Instances of Teacher Reflection

Code	Description
Doubt/Perplexity	Participant expresses uncertainty about existing knowledge of a NOS or SI aspect from NOSSE Guide or others' ideas. *Example:* "I don't know if…because it says on here 'though traditional experimental designs typically include one, it is not necessary or typical of other designs' so I'm real specific on like what other designs? Or other descriptive…do you see what I mean? So, um, I don't know." *Diane after reading the NOSSE Guide for Scientific Investigations Begin with a Scientific Question*
Hesitation	Participant pauses and reconsiders a statement about a NOS or SI aspect, either from NOSSE Guide or another student. *Example:* "I think they are looking at them as two separate entities. I feel like maybe they are, [pause] they are looking at these as two separate things, that's why…hmmmm." *Diane, examining student VASI data for Data Differs from Evidence*
Searching for Facts	Participant searches or is directed to search for facts about NOS or SI from the NOSSE guide, from others, or from their prior experiences. *Example*: "I'm thinking something concrete for data. Like, how many people have gotten sick after being exposed to something to specific. We've got our data. But then that data can conclude, this is evidence, that this… Here's the data, the concrete data, the information to prove this claim, which is also evidence, like here's the evidence that proves it. That's why I say that even though it says that they are two different things, they go hand in hand. *Diane, giving an example to support her placement of a student exemplar response for the SI aspect, Data Differs from Evidence*

(continued)

Table 4.6
continued

Code	Description
Deliberation	Participant evaluates different or alternative ideas about NOS and SI aspects, then integrates new knowledge about NOS and SI with what is already known to make a decision; Carefully analyzes information to come to a conclusion about a NOS or SI conception. *Example:* "Yeah? I guess? I mean, I just think about the bone structure. You could say that it was this big or this long you might not know exactly the color like you said or the type of skin, but you can come up with some idea of what it looked like." *Tracy, on whether scientists know what dinosaurs looked like.*
Meaning-Making	Participant rephrases NOS or SI idea; may provide an example from their experience or try to make sense of other people's NOS or SI viewpoints to comprehend ideas that are contrary to their current understandings or beliefs. May make comparisons to make sense of NOS or SI ideas. *Example:* "So the tentative portion would represent the fact that it can change and the durability part would represent the fact that some things are not likely to change, being a fact that we've been seeing it happen and it has been tested so many times." *Tracy, determining the meaning of tentative and durable while summarizing the Tentative yet Durable NOSSE Guide*

(continued)

Table 4.6 continued

Code	Description
Rigor of Thinking	Participant is systematic in reasoning about NOS and SI by connecting the ideas from NOSSE Guides to their thinking and experiences; provides clear explanation for conclusion about NOS or SI conception. *Example:* “I guess what they are saying in here is you have to have some type of prior knowledge in order to generate your question. So if you are watching a baseball game you can make it scientific because you can think of ‘how fast is that ball going?’ and then you have to think of gravity and all of those other factors, so you can make it scientific in that way.” *Tracy, Placing a student exemplar for the aspect, Scientific Investigations Begin with a Scientific Question*
Reconsideration of Existing Knowledge	Participant makes a correction, or change, about a previous statement or action describing or explaining a NOS or SI aspect. Example: “I would put this student closer to this side because the other students have, well, more or less these students have noticed that in order to do a scientific investigation, you don’t have to have a question, you can make an observation, use your prior knowledge to generate a question. This student is making me feel like, like I don’t know, that science is just cut and dry and in order to do an investigation you need a question so that then you can go and research that information about that question. Not having any experience or prior experience or prior knowledge, to me its just like, ok, yeah you need a question just so you can have something to go research and learn about.” Tracy, moving a student exemplar card and reconsiders needing a question to guide investigations.

(continued)

Table 4.6 continued

Code	Description
Affirmation	Participant agrees with a statement about NOS or SI and/or acknowledges a previously stated NOS/SI idea from another person or the NOSSE Guide. Example: "I like this one [student exemplar response]. I put this one in more like the standards. He's got, it says data is being investigated or collected. It's different from evidence because, and I like that it says data is collected and evidence collected to support a claim based on data. So I think that is a little bit more like what the standard is asking for." Diane while placing a student exemplar card for Data Differs from Evidence supporting placement with information from NOSSE Guide**.**
Alternative Meanings	Participant suggests a different meaning for something regarding NOS or SI, something other than what was previously stated or as in NOSSE Guide. *Example*: "Well, I tell my students, an educated guess that means you aren't just popping something out, you need to have something, a basis or some type of evidence, not necessarily evidence, but you need to have scientific thought of why you chose what you did, so…" *Diane, providing an alternative meaning for hypothesis after reading the science begins with a question NOSSE Guide.*

Note. Examples provided from interviews with both Tracy and Diane while completing the NOSSE Exemplar Strategy. In previous iterations of the reflection coding scheme there was a category for "doubt" but this was combined with "perplexity" in this study because the two categories were synonymous when coding.

Results

The following section will present evidence that the NOSSE Exemplar strategy, as used in the current study, promoted teacher professional growth for NOS and SI. Overall, the NOSSE Guides (external domain) and student exemplar responses (domain of consequence) made aspects of NOS and SI explicit and prompted each teacher to reflect on their current conceptions of these constructs (personal domain). Instances of teacher reflection were coded from the conversation between each participant and the researcher as teachers engaged with the NOSSE Exemplar strategy. Coded instances of reflection were used to map IMTPG change sequences. In addition, changes in teachers' NOS and SI conceptions were visualized using professional growth diagrams and teachers' intent to integrate NOS in their classroom instruction was assessed. Together, this data will be presented and used to explain how, and to what extent, teacher professional growth occurred as a result of reflection on students' exemplar responses in conjunction with NOSSE Guides.

The Change Environment

Since teacher professional growth is influenced by the interaction of many factors within the teaching and learning environment, both interview and survey data were used to determine whether each teachers' change environment was supportive of teacher change. A bivariate categorization of science teaching self-efficacy and teacher beliefs about the supportive nature of their instructional context was used to describe teacher agency. The Environment Support Beliefs Scale (y axis) indicated how supportive the teacher perceived their change environment. The personal self-efficacy score (x axis) indicated how confident a teacher is in their ability to effectively teach. Both Diane and Tracy taught in change environments conducive to teacher professional growth. Both teachers in this study fell into the *robust* (high self-efficacy, very supportive context) category (Figure 4.7).

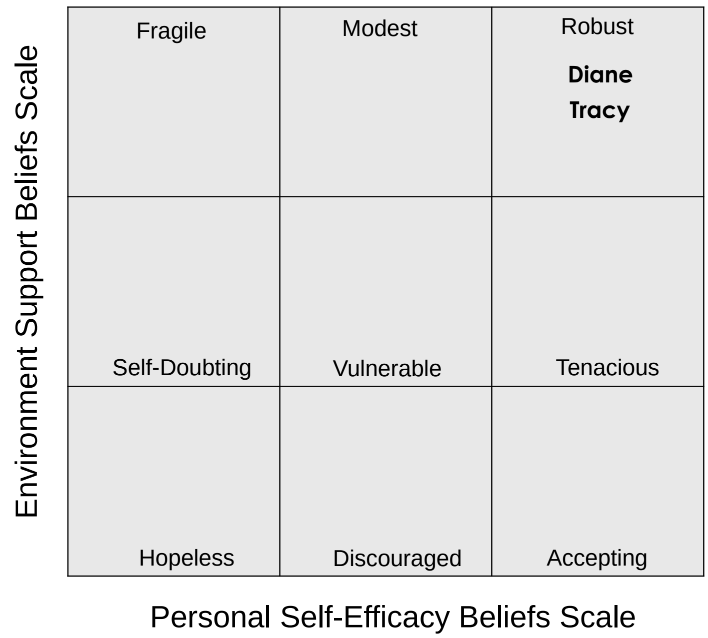

Figure 4.7. Description of support and ability beliefs for Diane and Tracy.

Tracy indicated she had the support of her principal to try innovative strategies that could benefit her students. She reported the only aspect of her teaching environment that constrained her ability to innovate were the strict pacing guides teachers in the district were required to follow. While teachers had the flexibility to use different pedagogical strategies and methods, the pacing guides dictated the order concepts needed to be taught and the amount of time that could be spent on each topic. This was evident in my first interview conducted with Tracy (preliminary interview, 8/16/2016).

Researcher: Do you feel like you are able to experiment and do what you think is best for your students?

Tracy: No.

Researcher: Tell me about that.

Tracy: The only reason why is because they want all the biology teachers to teach the same thing at the same time, whereas a couple years ago when I had my best year, I taught what I felt was comfortable for my students, I taught innate behaviors, interdependence, I just taught different things at different times. Now we have biology content meetings and we all have to teach this, we all have to teach that, I liked it more when I had more freedom to decide what I was teaching and when I wanted to teach it.

Researcher: Do you think you still have freedom within that sequence of when you have to teach it? Like if you all have to teach macromolecules, are you able to do it differently?

Tracy: No, I can teach it the way I want to teach it. Like I'm the only one who does PI [Peer Instruction]. I can do what I want, I just have to teach this particular topic first. I have to do everything that the other biology teachers are teaching. Before I just went with the flow. Gauged where students were and also, before when I was able to teach whatever standard I wanted to teach first, if I felt like I needed to go back and do it over or do some work on that particular thing I could but now I can't because we are all trying to follow this calendar. You need to have this done by two weeks and then we are moving on to this or we are moving on to that. So I don't like that aspect. Other than that I feel supported.

Diane also indicated she felt very supported by both her principal and fellow science teachers. In our first interview (9/1/2016) she reported she had the freedom to implement new strategies, but also felt somewhat constrained by the end of course (EOC) exams since students' scores accounted for a percentage of the overall course grade. Therefore, ensuring students were prepared for EOC exams was a major factor in how she approached instruction.

Professional Growth for NOS and SI

The following section will provide data to support the diagraming of change sequences for each participating teacher. I begin by discussing the data collected for variables that reside in each IMTPG domain (personal, practice, and domain of consequence) and any changes that occurred as a result of teacher participation in the NOSSE Example Intervention (external domain). These change sequence diagrams represent pathways of teacher professional growth that occurred through the mechanism of reflection. Results of Tracy and Diane's professional growth across four NOS aspects will be reported independently. Finally, data related to teacher intentions will be reported as a proxy for the domain of practice indicating how the NOSSE Example Intervention might have influenced teacher participants' desire to integrate NOS and SI instruction in their classroom practice.

Personal Domain

Changes in teachers' NOS and SI conceptions and intentions to integrate NOS in classroom instruction were assessed prior to and at the conclusion of the study (Table 4.7). Changes in conceptions that occurred were visualized using professional growth diagrams. Tracy's changes are shown in Figure 4.8 and Diane's in Figure 4.9. Overall, both teachers showed positive growth for NOS and SI conceptions as well as some changes regarding their intent to integrate NOS in future classroom instruction.

Table 4.7

Changes in NOS and SI Conceptions After Completing the NOSSE Exemplar Strategy

		No Single Scientific Method	Tentative but Durable	Data Differs from Evidence	Observations differ from Inferences
Diane	PRE	M	M	M	M
	POST	I	I	M	I
Tracy	PRE	N	M	M	M
	POST	M	I	I	I

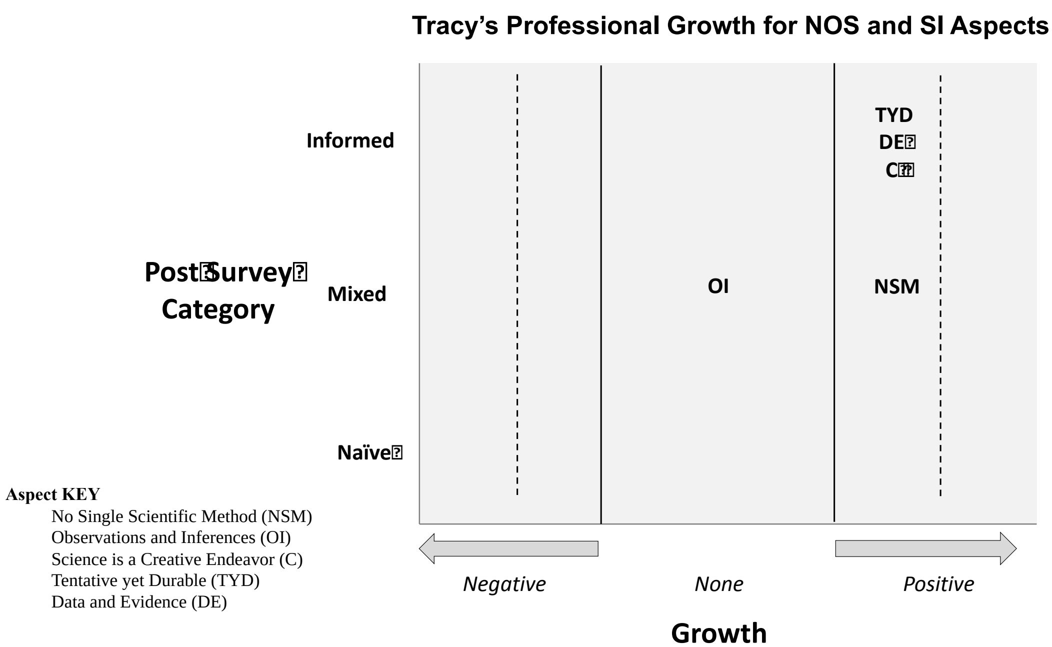

Figure 4.8. Tracy's professional growth for NOS and SI aspects. Tracy showed positive growth for all but one aspect. For tentative yet durable (TYD), data and evidence (DE), and creativity (C), she shifted from a mixed to informed view and for no single scientific method (NSM) she shifted from a naïve to a mixed view after completing the NOSSE Exemplar Strategy. Tracy did not show growth for observations and inferences (OI), maintaining a mixed view for this aspect.

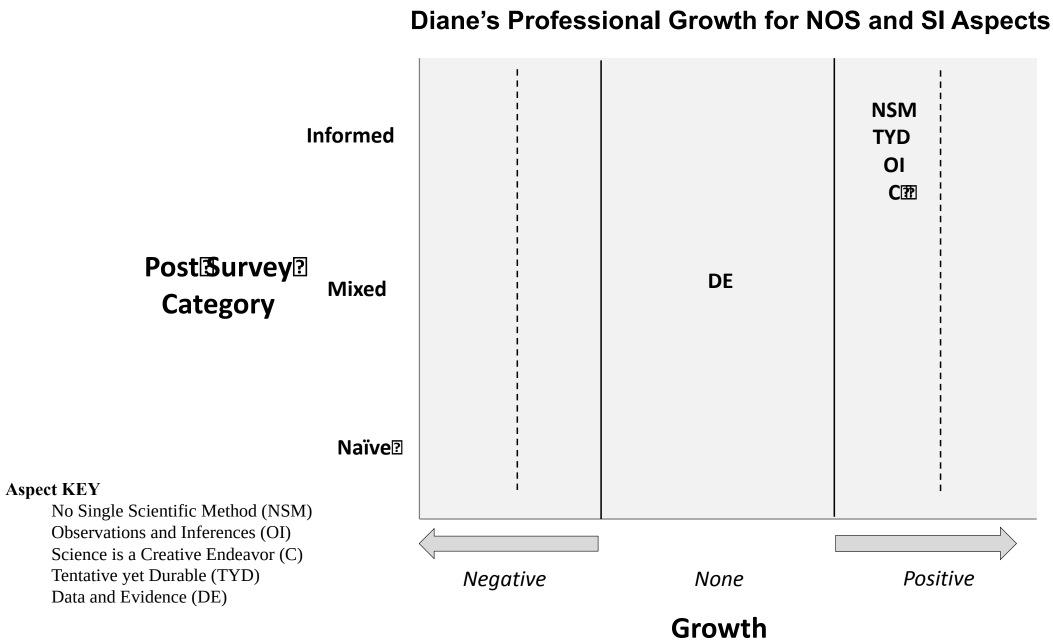

Figure 4.9. Diane's professional growth for NOS and SI aspects Diane showed positive growth for all but one aspect. For no single scientific method (NSM), tentative yet durable (TYD), observation and inference (OI), and creativity (C), she shifted from a mixed to informed view. Diane did not show growth for data and evidence (DE) and maintained a mixed view for this aspect.

IMTPG Change Sequences and Potential Growth Pathways

During the individual professional development sessions (external domain), each teacher was asked to summarize the NOSSE Guide and point out any information that was confusing or resonated with them. In some instances a teacher would highlight and write notes on the guide. In other cases they would indicate they agreed with the information presented (reflection). At times, teachers were completely perplexed by the information in the NOSSE Guides. Akerson, Buzzelli, and Donnelly (2008) reported that "we have found that most elementary teachers have not heard the term 'nature of science,' and when they see it in their state frameworks they misinterpret the term as meaning something to do with nature, not as the essence of science itself" (p. 748).

Indeed, prior to engaging in the NOSSE Exemplar Strategy, neither teacher could clearly articulate a definition for nature of science or had heard of most of the aspects presented in the NOSSE Guides. In an early one on one professional development session, Tracy admitted, “all of this is pretty new to me” after reading about observations, inferences, and creativity (interview, 1/20/2017).

Teachers were then asked to examine student exemplar responses (domain of consequence) and decide whether students’ NOS and SI understanding was more or less like the information presented in the NOSSE Guide. Each time a participant engaged in the NOSSE Exemplar Strategy, discourse was recorded, coded for instances of reflection, and used to create each IMTPG change sequence diagram presented below. Change sequences are numbered on the diagrams and then described in the text (e.g., reflective link 1, reflective link 2). For example, if teacher reflection on the NOSSE Guide (external domain) led to new, acquired knowledge about the NOS or SI aspect (personal domain), a reflective link would be placed between the two domains to indicate this change.

NOS Aspect 1: There is No Single, Set or Sequence of Steps in a Scientific Investigation

Tracy

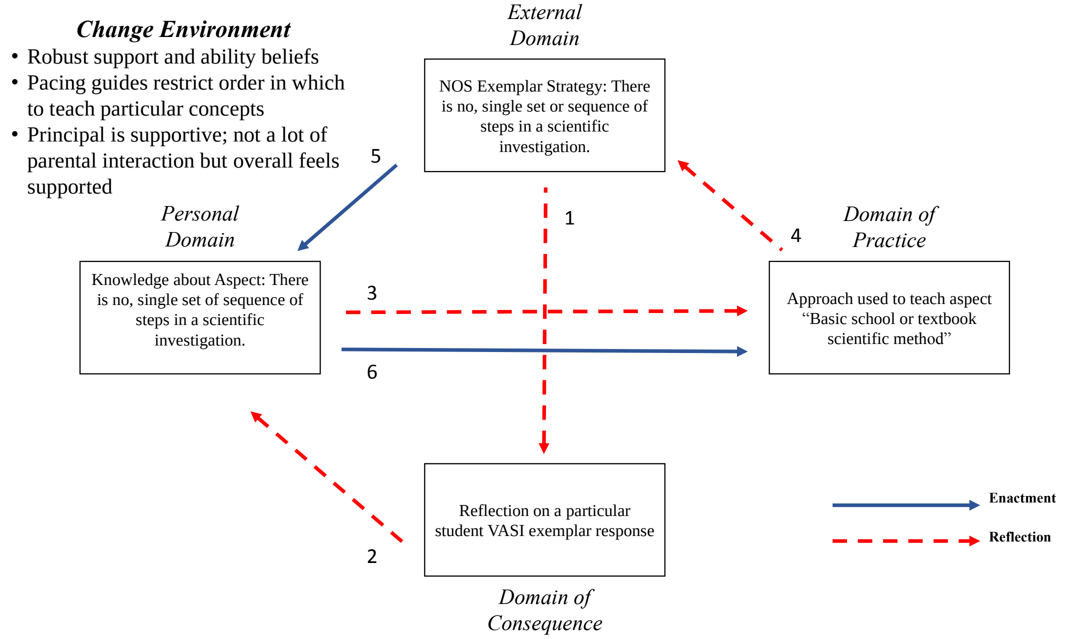

Figure 4.10. Tracy's change sequence: No single scientific method (NSM).

Tracy examined the NOSSE Guide for "No Single Scientific Method" (NOSSE Exemplar Strategy Session 1, NSM, 12/15/2016) and spent time highlighting and underlining information. She stated she agreed with the information in the NOSSE Guide but did not elaborate (therefore there was no initial reflective link between the external and personal domain for Tracy). When presented with three student exemplars, however, Tracy identified with one response (which represented a naïve view) as similar to her own understanding. The following dialogue describes how reflecting on this exemplar in light of the information in the NOSSE Guide enabled Tracy to reconsider her existing knowledge of the scientific method (reflective links 1 and 2 in Figure 4.10).

Researcher: I'm curious to know how you would rate your students' understandings of the NOS ideas you just read [hands teacher three exemplar response cards].

Tracy: This response looks like mine [points to response from Student 1]…this is a student right?

Researcher: Yes, this is a student. One of your students.

Tracy: Student 1 looks like my answer. [She reads the other student responses aloud].

Researcher: How would you rate each of these students' understandings based on the standards [NOSSE Guide]?

Tracy: Ok. Hang on. Am I basing it on your introduction [points to NOSSE Guide] or how do I word it, basic science curriculum that I teach in my classroom?

Researcher: How about tell me both? That would be a great comparison.

Tracy: The basic way is going to tell you the purpose, research, you know…that's what we teach them and what they see on assessments. It is what is in textbooks. If I base this student response [holds up response card for Student 1] on the school's definition [pause] it is different from this [points to guide sheet].

Researcher: How would you rate [the level of] their understandings? Low? Medium? High?

Tracy: Oh, ok. If we are basing it on the schools definition, um, societies at this point. I guess this is a new idea [points at guide sheet] that you are trying to develop?

Researcher: It's new in the sense in that there has been a really difficult time getting what science really is into school science and standards documents.

Tracy: So I'd say this is how I would put them (See Figure 4.11).

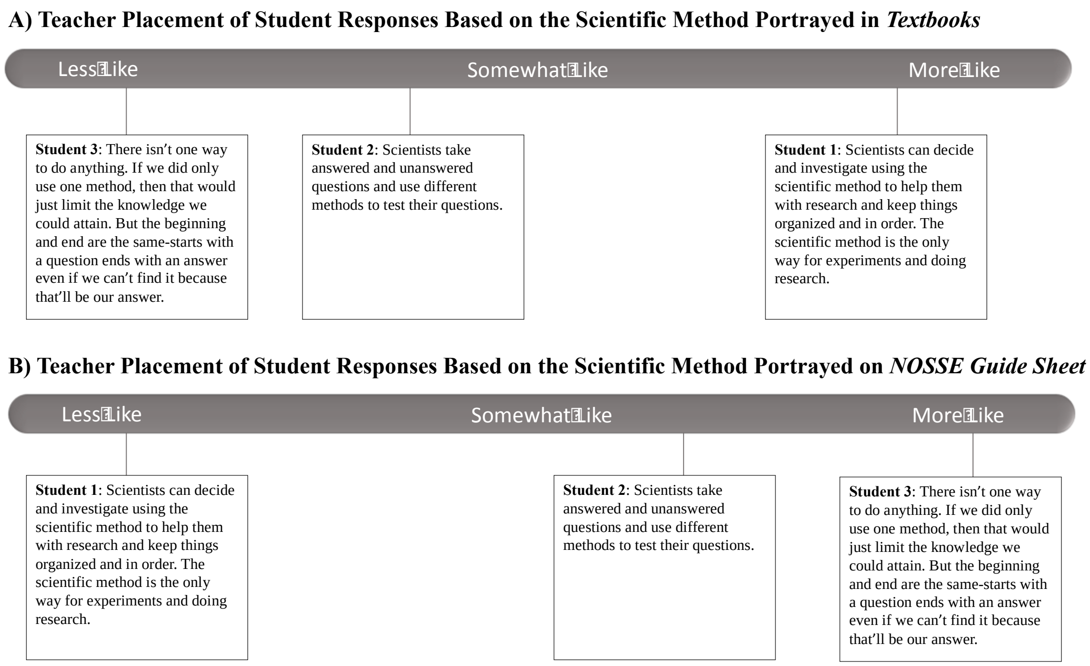

Figure 4.11. Tracy's placement of student exemplar responses to the question, "Do you think that scientific investigations can follow more than one method?" (Abridged Student VNOS/VASI/VOSI Survey, question 3). Placement A) was based on how the scientific method is portrayed in textbooks, while placement B) was based on the NOSSE Guide.

Tracy recognized a discrepancy between the information presented in the NOSSE Guide and the view of the scientific method presented in her science textbooks and teaching resources (reflective link 3, Figure 4.10). Tracy spent time reflecting on how the NOSSE Guide was different than information in textbooks (reflective link 4) and then this led to a change in her knowledge about this aspect (enactment link 5) and how she would rethink presenting the scientific method posted on her classroom wall (enactment link 6).

Tracy placed the student exemplar response cards in two ways: first using a view about the aspect from the "school" science perspective of what is presented in her textbooks (Figure 4.11, A) then by using the view presented in the NOSSE Guide (Figure 4.11, B). She recognized she held similar views as Student 1, and placed this response as "more" based on the typical view of the traditional scientific method presented in her textbooks and teaching materials. However, when she used the NOSSE Guide, she moved this response to "less" like the NOSSE Guide. This cognitive conflict allowed Tracy to carefully reflect on her conceptions of the scientific method. I brought this to Tracy's attention and she explained:

> Tracy: It [placing the cards in opposite to the NOSSE Guide] is based on what we tend to teach our kids, based on the curriculum, based on what we've learned and new ideas. So it [information presented in NOSSE Guide] is really just showing you that we as science teachers are not progressing, we aren't being told or teaching our students these new concepts and ideas. We are doing the same old, cookie-cutter activities… I mean, we just began, but I can see where…just having this idea I think it would get more kids interested in science.
>
> Researcher: How so?

> Tracy: Um, because it’s not boring. Like when you have to follow these steps and start here…but when you look at it that you can start anywhere you want it becomes more exploratory.

Tracy’s realization that her own understanding of this SI aspect was incongruent with the information presented in the NOSSE Guide resulted in a shift from holding a naïve view about this aspect to a mixed view (personal domain, Figure 4.8.) When asked whether the development of scientific knowledge required experiments on the VOSI-270 post assessment (taken 2/2/2017), Tracy wrote: “Not necessarily. Scientific knowledge can be acquired through observation. For instance, someone can make an observation that plants grow better in warm and humid environments versus colder environments by just looking and comparing the size of the plants.”

After completing the NOSSE Exemplar Strategy on multiple methods with Tracy, I stayed for a classroom observation (12/15/2016) of a lesson on identifying macromolecules. Students were given detailed instructions how to test and identify each of the “mystery” substances as a carbohydrate, lipid, or protein. Students busily filled test tubes with mystery substances and indicators and completed the data table as instructed. I walked around the room and asked each lab group, “What question is guiding your investigation?” Not one student group could articulate the scientific question they were attempting to answer and only one student was able to tell me the purpose in what they were doing (trying to identify unknown macromolecules). It should be noted that this NOS aspect was not one explicitly addressed in this study. However, I had discussed this aspect with Tracy prior to her completing the ‘No Single Method’ NOSSE Exemplar session. I brought to Tracy's attention that her students were unable to identify the purpose or question being addressed by the activity. She was surprised, so after the lesson we met and debriefed how the macromolecule lesson could be changed to explicitly include aspects of SI.

Tracy was part of a larger research project where she helped develop and use ConcepTests during Peer Instruction. Peer Instruction utilizes ConcepTests to facilitate student conceptual learning (Mazur, 1997). ConcepTests are multiple-choice questions that focus on a single scientific concept. Distractors on the ConcepTests are built from prior student misconceptions. Therefore, we discussed how she might be more explicit about SI aspects and give her students opportunities to reflect using ConcepTests. During this discussion, we came up with possible distractors for the ConcepTests based on her students' discourse during the macromolecule lab. For example, Tracy said she could pose the question, "What question guides the macromolecule investigation?" and provide students with the following choices:

1) What are different types of macromolecules?
2) How do macromolecules react in water?
3) How can we identify macromolecules?
4) What happens when we combine macromolecules with different solutions?

These ConcepTests choices were based on student responses we heard during the activity when we probed students to identify the question they were trying to ask. If this ConcepTest was used in conjunction with the macromolecule activity, students would 1) be explicitly introduced to the SI aspect that questions guide scientific investigations and

2) reflect on the SI aspect in the context of the macromolecule activity. This particular ConcepTest might enable Tracy to transform a cookbook recipe-type classroom activity into a means to enable students to “learn science in a way that reflects how science actually works” (NRC, 1996, p.214). Tracy’s attempt at creating a ConcepTest was the only instance during the testing of the NOSSE Exemplar Strategy in which the domain of practice was involved in a change sequence (enactment link 6, Figure 4.10).

Diane

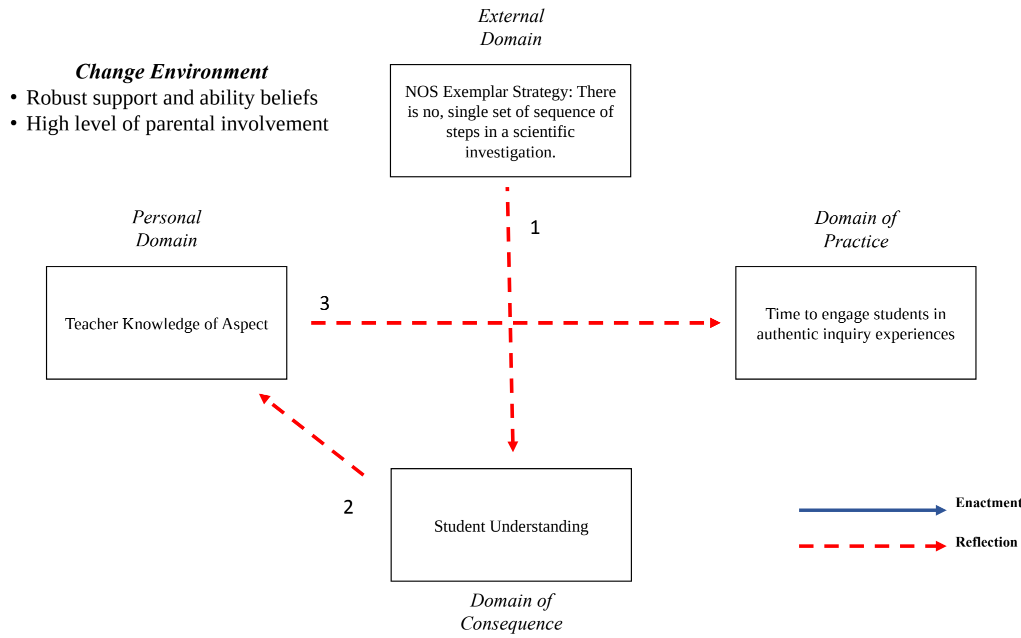

Figure 4.12. Diane’s change sequence: No single scientific method (NSM).

When Diane was given the NOSSE Guide for “No Single Scientific Method” she read the document and simply responded, “Wow.” (NOSSE Exemplar Strategy Session 1, NSM, 11/29/2016). Her confused expression indicated to me that she had not thought about the scientific method in the way presented in the NOSSE Guide. Her response on the VOSI-270 pre-assessment (10/1/16) confirmed that she did not hold views of the scientific method congruent with the NOSSE Guide. Her response to the question, “Do you agree that to do good science scientists must follow the scientific method?” was, “No (there are many scientific methods) I was always taught of these specific steps you must take to find the answer to your question. But I recognize that it doesn’t always work this one, same way. A lot of times you are going to go back and change your hypothesis and definitely change variables which would have you taking different steps.” After allowing her to re-read the NOSSE Guide, I asked, “Do you ever teach about science that is *not* experimental in your class?” After a long pause, she responded, “I’m trying to think specifically and I can’t think of anything.” Diane reflected on the information in the NOSSE Guide (external domain) in light of the learning goals she had for her students (domain of consequence). This is indicated by reflective link 1, Figure 4.12.

I presented Diane with six student exemplar responses in which students had answered the question, “Do you think that scientific investigations can follow more than one method?” She was asked to compare these exemplar responses to the NOSSE Guide. Her placement of the exemplars is shown in Figure 4.13.

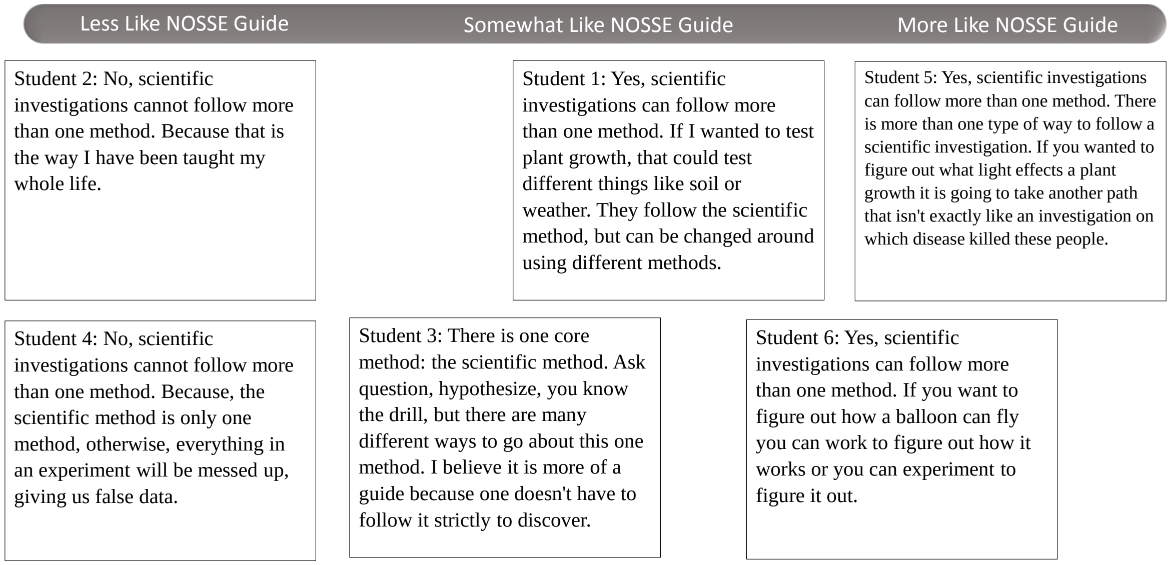

Figure 4.13. Diane’s placement of student exemplar responses to the question, “Do you think that scientific investigations can follow more than one method?” (Abridged Student VNOS/VASI/VOSI Survey, question 3).

Diane’s placed the exemplar responses in comparison to the NOSSE Guide. I redirected her to the guide when she seemed undecided where a particular exemplar should be placed. In this regard, she was reflecting on her knowledge of this SI aspect as well as constructing knowledge from the NOSSE Guide (reflective link 2, Figure 4.12). Diane reflected on her students’ conception of this SI aspect by noting that if students were given more opportunities to engage in scientific inquiry they might be able to better understand there is more to science than the steps they were taught in school (reflective link 3). When Diane saw Student 2’s response, she responded excitedly, “Oh my gosh! Because that is the way I have been taught my whole life?” I asked her, “What does that say to you?” She responded, “There’s no thought, or inquiry provoking [trails off]…this is what I’ve been given and this is all I know. RRAW [indicating frustration].

At this point, Diane had already placed Student 1's response as "somewhat like" along the continuum. However, she was so frustrated by Student 2's response she forgot that she was supposed to place the card. I prompted her with, "Would you rate that as sophisticated or not sophisticated?" Even though in our initial discussion of the NOSSE Guide I had explained that the views in the guides were what we might call sophisticated, Diane asked, "Well, when you say sophisticated, what do you mean?" I responded, "I mean matching the standards [NOSSE Guide]." Diane [mutters to herself] "what the standards say…" Then she exclaimed, "Well, hold on, he's… it doesn't match! It is not sophisticated in that it doesn't match this [NOSSE Guide]…and I guess the first one doesn't necessarily match it either." It was at this point that Diane had reflected and internalized the meaning of what it meant to hold a sophisticated view of this SI aspect (further evidence for reflective link 2, Figure 4.12). This cognitive dissonance had not occurred when she read the NOSSE Guide, or even when she tried to identify an example of a way that scientific knowledge did not use experiments. To probe further, I asked Diane to look at Student 3's exemplar. She recognized this response represented the information in the NOSSE Guide more so than the others, but she wanted her student to provide an example to really show sophisticated understanding. She revealed that the reason she did not think that her students all showed a sophisticated view for this aspect was that they were rarely given the opportunity to conduct their own investigations and explore scientific questions (more supporting data for reflective link 3, Figure 4.12). This was evident in the following exchange between us.

Diane: Even, everything, anything we do in here I'm giving it to them. I already know what the outcome is going to be … I know this and I'm giving you this lab and this is what's going to happen, if it doesn't happen it's ok. So I've tried, that's something I've tried to emphasize a lot before… [looks at Student 4's response] So that's way, again, there's a trend. Like they are all…low. I'm trying to think back to when I was in high school, was I given that opportunity [to do scientific investigations]? It wasn't until I was in college. And I remember [in] microbiology you had to come up with something… Everything is given everything is given there's nothing, no room for exploration whatsoever [referring to the classes she teaches]. I don't know, there's not time. I hate that I keep saying time, but you, we have such a time crunch, we have to cover this this this and this.

Researcher: Why?

Diane: Yeah, it's all on the big test at the end. It's all testing.

Diane also expressed interest in seeing more of her students' exemplar responses. I told her that I had an entire spreadsheet of her students' responses and she replied, "the data is really interesting to me." Diane's engagement with the student exemplars and NOSSE Guide resulted in overall positive shifts in in her knowledge about NOS and SI aspects addressed in this study (Figure 4.9).

NOS Aspect 2: Inference, Imagination, Creativity

Tracy

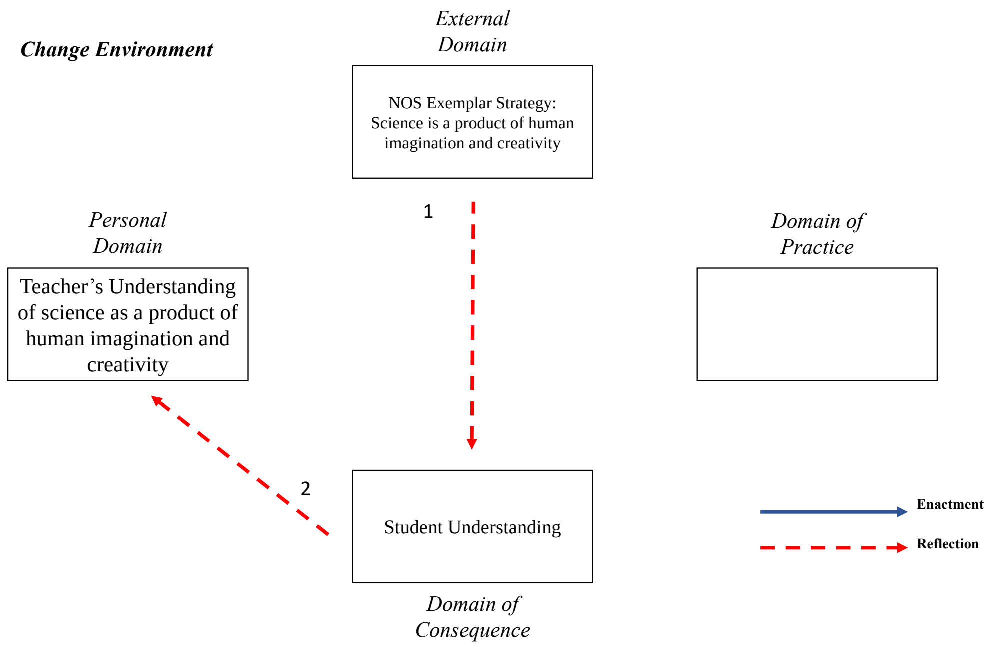

Figure 4.14. Tracy's change sequence: Science is a product of human imagination and creativity (C) and observations and inferences (OI).

Tracy spent time highlighting the NOSSE Guide sheet (NOS Exemplar Strategy Session 2, OI, 1/20/2017). She started the strategy by stating, "What I really got from this [NOSSE Guide] is that basically… we [teachers] don't really press the notion that science involves creativity and imagination. And that maybe some of the reasons kids don't like science and they think it is boring because we don't press those issues." The NOSSE Guide (external domain) spurred Tracy to reflect on her desire for students to view science as a creative endeavor (domain of consequence) to increase their interest in science (reflective link 1, Figure 4.14). A few minutes later she stated she agreed with the information in the guide and said:

> If we could find a way to really allow kids to have that creativity and use their imagination, I think they would enjoy science more, but I think a lot of it, a big part of the problem are the EOC's. We as teachers don't really have the opportunity, with the EOC with all the meetings with all this…like this week I've had a meeting every planning period, so you know, between meetings and standards and common core, you really don't have the time to allow kids to be creative and use their imaginations. Because we are trying to teach them this information so they can pass a test at the end of the year. (NOSSE Exemplar Strategy Session 2, OI, 1/20/2017).

After this discussion prompted by the NOSSE Guide, Tracy was given five exemplar responses where students were asked, "How certain are scientists about the way dinosaurs looked?" Her placement of them along the continuum is shown in Figure 4.15. Her reason for placing Student 2 as "less like" was because "they [scientists] had bones…you know, to figure out the structure." She used this reasoning for placing Student 3 as "more like" and noted that this response was similar to her thinking because "they [Student 3] basically said what I just said (further evidence for reflective link 1, Figure 4.14). You can kind of determine how they physically looked due to the bone structure and you don't know the color but we know that certain animals have camouflage so it fits that whole idea that animals, which would be more of a…defense mechanism." Tracy's engagement with the student exemplars and NOSSE Guide sheets resulted in a positive shift in her knowledge about science as a creative endeavor (reflective link 2, Figure 4.14), though it should be noted her views of observations and inferences did not shift in either the positive or negative direction.

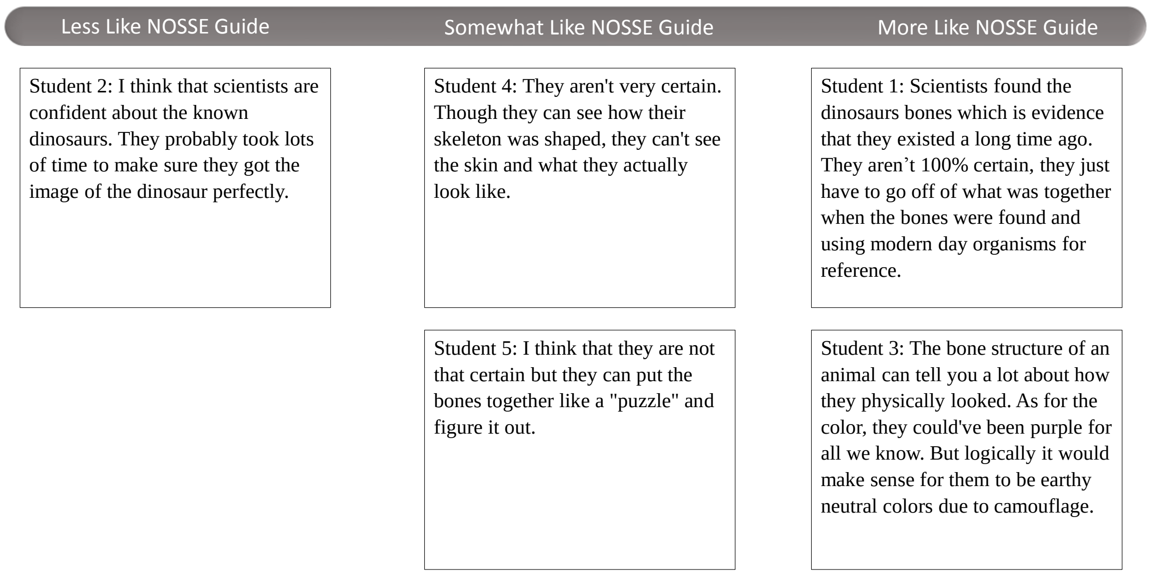

Figure 4.15. Tracy's placement of student exemplar responses to the question, "How certain are scientists about the way dinosaurs looked?" (Abridged Student VNOS/VASI/VOSI Survey, question 8).

Diane

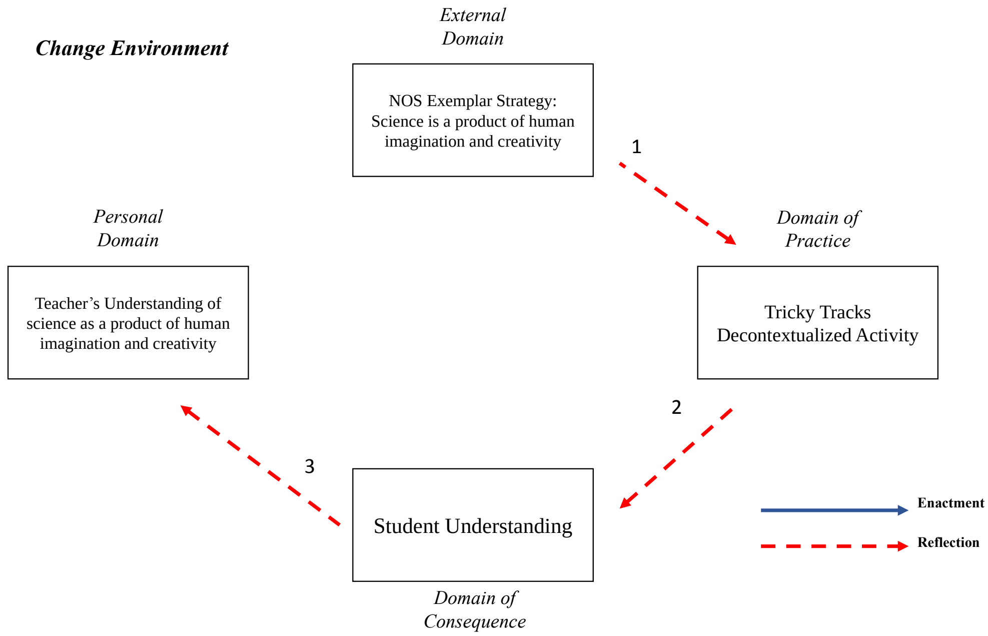

Figure 4.16. Diane's change sequence: Science is a product of human imagination and creativity (C) and observations and inferences (OI).

Immediately after Diane read the NOSSE Guide for the aspect that science is a product of human imagination and creativity and the distinction between observations and inferences, she identified that the information in this guide was similar to an activity she taught (NOSSE Exemplar Strategy Session 2, OI, C 1/19/2017). She explained how she included the activity "Tricky Tracks" in her scope and sequence because "the kids, the things that they come up with… one was the mom and one was the baby and they flew off. Or one was the predator…just the craziness! So that's why with this one [points to NOSSE guide sheet] like right here it says, 'several observers can reach agreement with relative ease' but I feel like there are so many things that you can't because people perceive things differently" (reflective link 1, Figure 4.16).

Diane's placement of the exemplars is shown in Figure 4.17. Note that the student exemplar cards for Diane are the same as for Tracy as the researcher mistakenly used Tracy's cards for Diane in this instance. This mishap turned out to be interesting as the teachers placed the exemplars differently despite having the same information.

Diane placed Student 1 as "more like" the NOSSE Guide because even though there is never 100% certainty, the student stated that scientists use the evidence available today and use creativity to develop a plausible explanation. She described Student 2's use of the word "perfect" as the reason she placed that particular exemplar in the "somewhat like" area. She even described how this response was similar to the use of models as a means to describe and explain rather than to be perceived as an exact replica of a natural phenomenon (reflective link 2, Figure 4.16). She stated, "just like when we go over the atom or we go over the cell, it [the model] is not exact, it's not." As Diane placed Student 3's exemplar response (Figure 4.17) she noted:

> I like this. I like it because they are, they have the evidence, which is showing here's the evidence. We can use our creativity and assume this is what it [a dinosaur] looks like based on the physical evidence, but this is good too. You really don't know so they [the student] are letting you know it's not perfect, you don't know. And then the whole camouflage thing kind of threw me off. But then we are going back to a bigger idea of how they existed, or natural selection. So there's a lot of things going on there so I feel like even though it's kind of crazy, I like the explanation so I'm going to put it 'more like' [the NOSSE Guide] because this is saying we know it, here's the physical structure, but there are still things

we don't know. I like that. I like that. We do have some evidence…and then some stuff we've got to look at other things.

Diane's engagement with the student exemplars and NOSSE Guide resulted in a positive shift in her knowledge about science as a creative endeavor and her views of observations and inferences, specifically in relation to the Tricky Track activity she uses with students (reflective link 3, Figure 4.16).

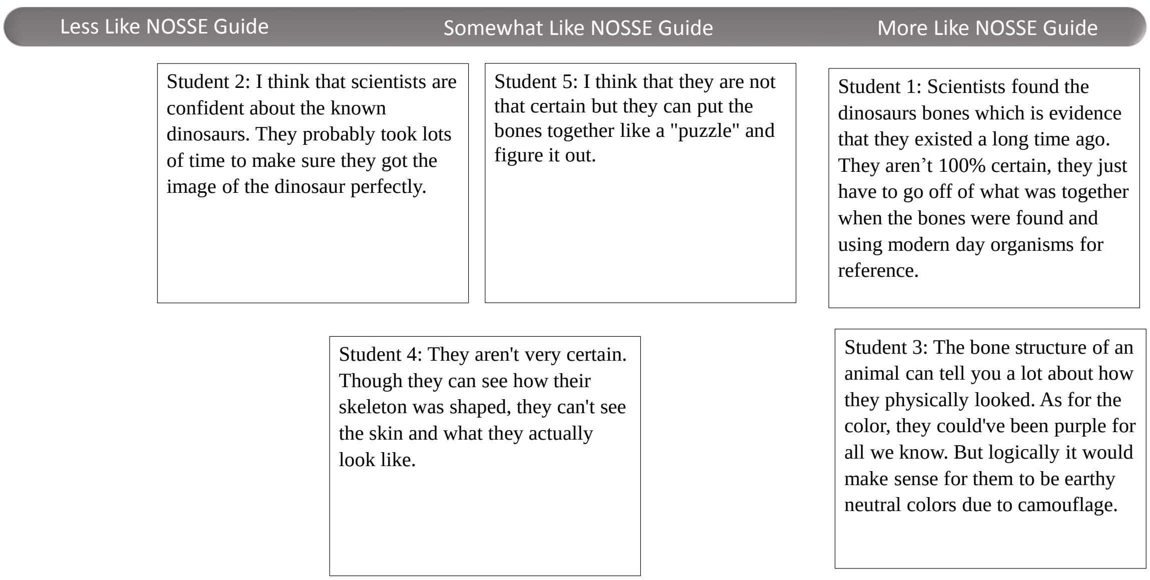

Figure 4.17. Diane's placement of student exemplar responses to the question, "How certain are scientists about the way dinosaurs looked?" (Abridged Student VNOS/VASI/VOSI Survey, question 8). Note that the same student exemplar cards were used by both Tracy and Diane for this aspect.

NOS Aspect 3: Tentative yet Durable

Tracy

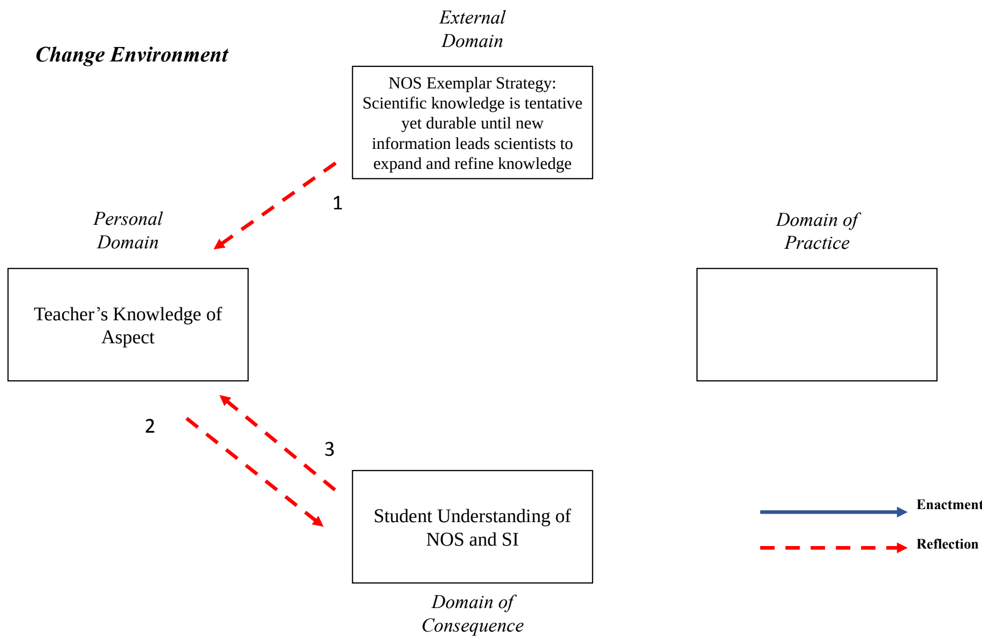

Figure 4.18. Tracy's change sequence: Scientific knowledge is tentative yet durable (TYD).

Tracy's examination of the NOSSE Guide and her students' exemplar responses enabled her to better understand the idea that while scientific knowledge is tentative and can change, this idea is incomplete (NOSSE Exemplar Strategy Session 3, TYD, 1/20/2017). This occurred when she reflected on Student 3's response. She placed this as "more like" and noted, "so the tentative portion would represent the fact that it can change and the durability part would represent the fact that some things are not likely to change, being a fact that we've been seeing it happen and it has been tested so many times" (reflective link 1, Figure 4.18). Changes in her knowledge about the tentative yet durable nature of scientific knowledge enabled her to reflect on her students' views of NOS contained in the exemplar responses. Tracy was particularly impressed with one of her student's responses that included reference to the Higgs boson particle (Student 4, Figure 4.19). Tracy explained that she did not know this student (and others) held such detailed views about this NOS and SI aspect (reflective link 2, Figure 4.18). Tracy's reflection on the student exemplars and NOSSE Guide resulted in her thinking about what views her students should strive for (domain of consequence) and resulted in a positive shift in her knowledge about the tentative yet durable nature of scientific knowledge (reflective link 3, Figure 4.18).

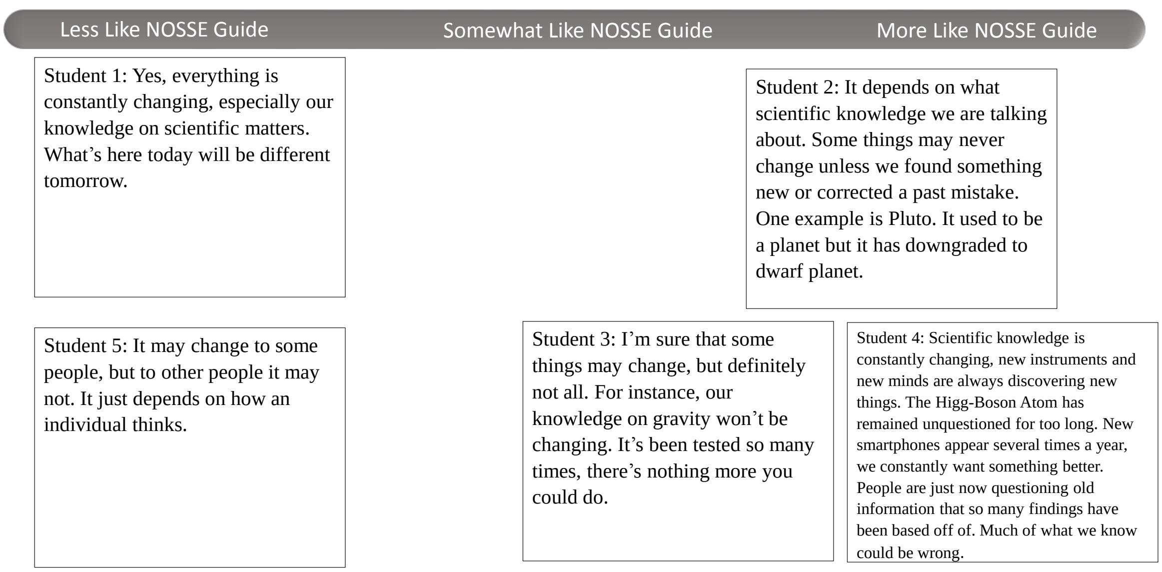

Figure 4.19. Tracy's placement of student exemplar responses to the question, "Scientists produce scientific knowledge. Do you think this knowledge may change in the future?" (Abridged Student VNOS/VASI/VOSI Survey, question 6).

Diane

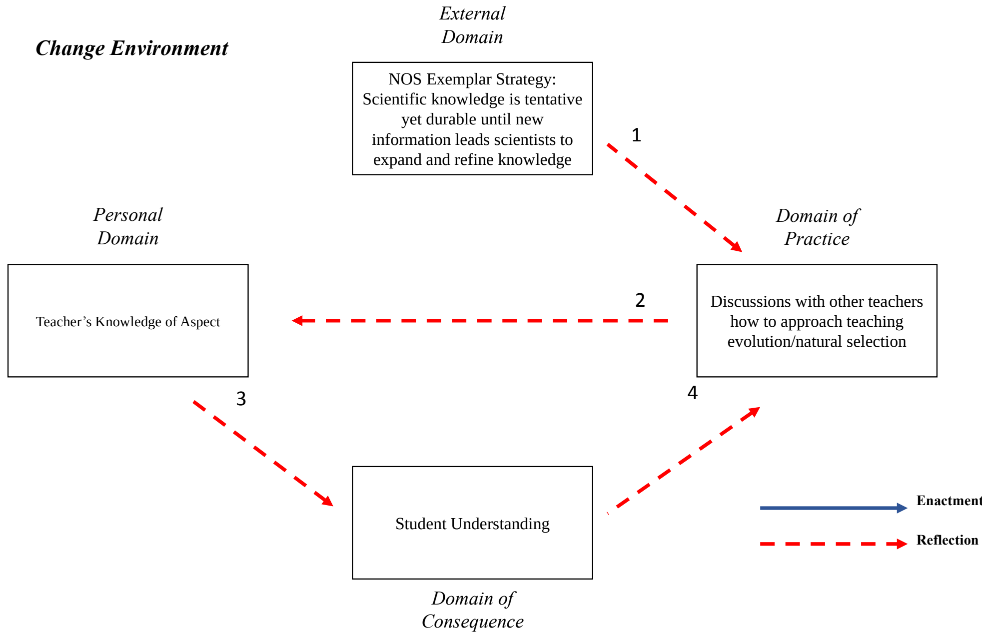

Figure 4.20. Diane's change sequence: Scientific knowledge is tentative yet durable (TYD).

About a week prior to me going to Diane's classroom to address the tentative yet durable NOS aspect, Diane emailed requesting an entire article discussed during the VNOS/VOSI follow-up interview (*Teaching About Evolution and Nature of Science*, National Academy Press, 1998). I sent this to her, and after Diane read the NOSSE Guide (which included a small excerpt from this article), she shared with me that it reminded her of what I had sent. She said, "I actually shared [it] with a couple of other teachers about teaching evolution. [The] new teachers were like, she's fantastic [regarding a vignette that describes one teacher's approach to teaching evolution]. Because a lot of teachers are scared to teach, so I'm interested and I'm sitting and reading the article and it is interesting because it says 'does that mean evolution will be replaced by a better theory someday?' So I'm going off of, would this, talking about fossils and biochemistry and evolutionary changes I think absolutely, but when people see the word evolution they just think "monkey"! (NOSSE Exemplar Strategy Session 3, TYD, 1/19/2017). This represented reflective link 1 (Figure 4.20) between the NOSSE Guide (external domain) and that changed her interactions in the community of teachers to include discussion about this NOS aspect (domain of practice).

Diane began placing student exemplar responses and thought of evolution as well as what was contained in older textbooks:

> This one [Student 1] is more like the standards [NOSSE Guide] because, not just because they were talking about evolution, but they're finding new evidence, they are proving this is what we thought…and this is, you know, this is what I tell the kids all the time why I love to teach science, and not math, is because it [science] is always changing. We can't teach about planets the same way we did 10 years ago. For me though, I collect textbooks and I started collecting nursing textbooks, old textbooks that were my grandmother's and mother-in-laws' because when you look at those books, even in that realm of science, the books now have to constantly be updated every year because the information changes. It always changes.

Student 4's response contained the word "opinion" and Diane mentioned that she placed this response as "somewhat" because she disliked the student's use of the word opinion rather than evidence. At the end of the session, I asked Diane to tell me about what she thought about her students' responses. She responded:

[They] made me think more about this [NOSSE guide] (reflective link 2, Figure 4.20). I love the way they [students] answered the questions and I'm surprised (reflective link 3, Figure 4.20)… I think they are all smart enough to know that things can continue to change. I think they have enough knowledge of science to know that it is every changing. But knowing this [points to NOSSE guide] I can approach some things a little differently, like certain concepts. Even like when I teach natural selection" (reflective link 4, Figure 4.20). Both Diane and Tracy noted they were surprised at the depth of knowledge their students possessed about the tentative yet durable nature of scientific knowledge.

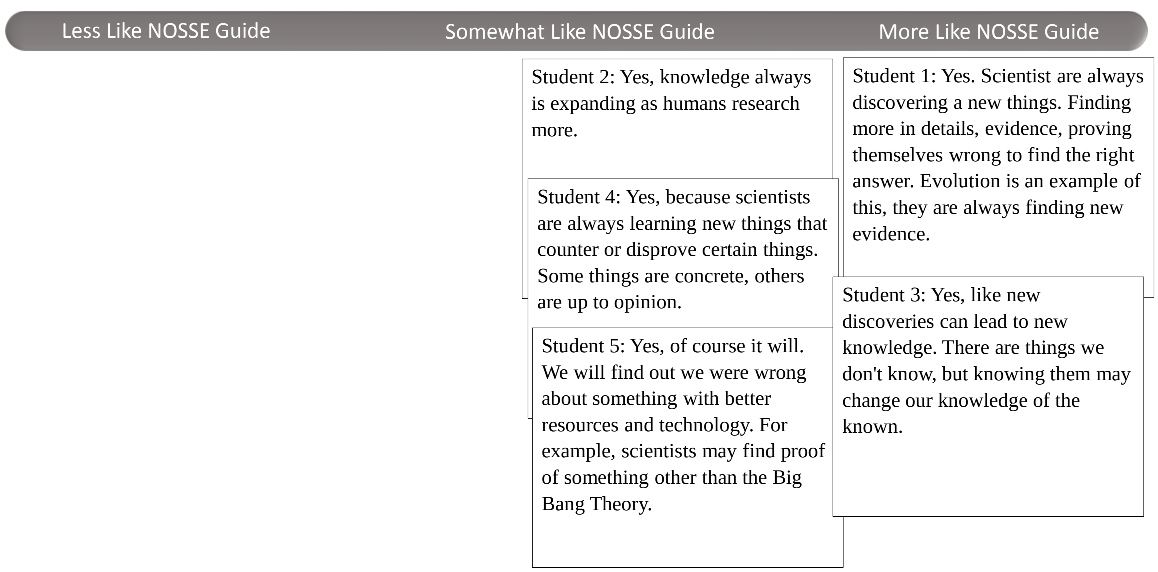

Figure 4.21. Diane's placement of student exemplar responses to the question, "Scientists produce scientific knowledge. Do you think this knowledge may change in the future?" (Abridged Student VNOS/VASI/VOSI Survey, question 6).

Diane's reflection on the student exemplars and the NOSSE Guide resulted in a positive shift in her understanding about the tentative yet durable nature of scientific knowledge.

NOS Aspect 4: Data & Evidence

Tracy

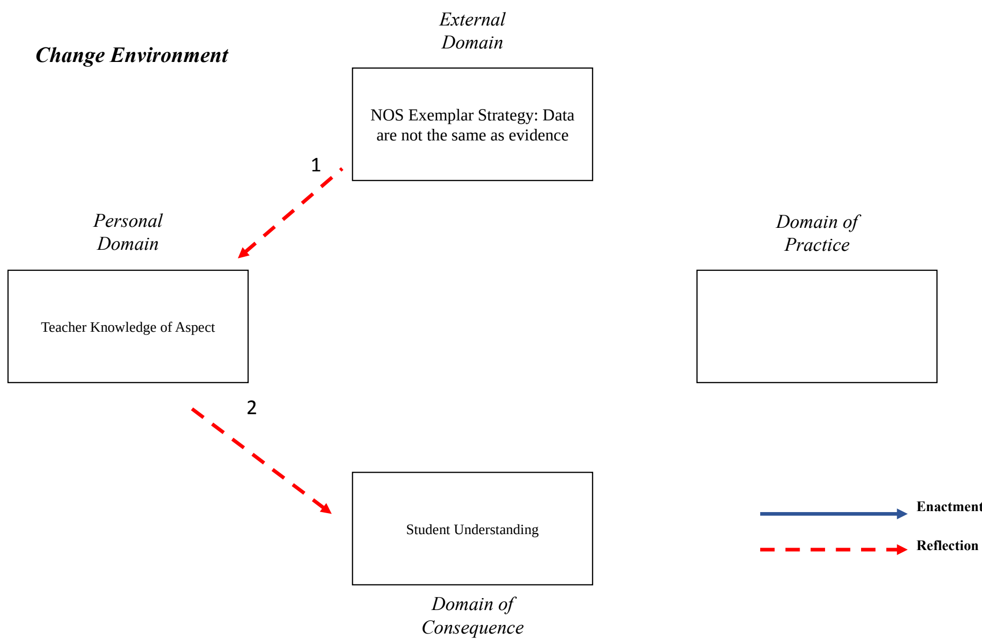

Figure 4.22. Tracy's change sequence: Data are not the same as evidence (DE).

Tracy read the NOSSE Guide about the distinction between data and evidence, and when asked to describe what stood out to her she responded, "Data is what is collected, evidence is the result, the evidence is the result of what is collected but it is tied to some question the scientist was trying to ask" (NOSSE Exemplar Strategy Session 4, DE, 2/3/2017). This indicated a reflective link between the external and personal domains, as she reflected on the distinction between data and evidence (reflective link 1, Figure 4.22). I had compiled her students' responses and generated a graph to show how many of her students stated data was the same as evidence (n = 24) and how many viewed data and evidence as different, a view congruent with the NOSSE Guide, and were able to describe why (n = 40).

When showed this graph, she was pleased that forty of her students said they were different. I then showed her each of the six student exemplar responses and asked her to place them along the continuum. She placed students 1, 2, 3 and 5 toward “more like” the NOSSE Guide and students 4 and 6 toward “less like” for the reasons below. She was able to clearly articulate her exemplar placements, indicating a reflection on the NOSSE Guide promoting changes in her understanding of this NOS aspect (reflective link 1, Figure 4.22).

More Like:

[Student 1] “Well, they know what data is and then they said evidence is something that can prove, so again, you are looking at that data but at the same time, this student understands that you are trying to solve a problem or prove something with that data. So that would be evidence to me.”

[Student 2] “I think they may mean that whoever is analyzing the data can kind of tailor it to prove or disprove what they want you to know.”

[Student 5] “Their example threw me off. But they have the right idea. They know the difference between data and evidence.”

[Student 3] “If it is used to prove one side it may be a bit different [pause]. What do you think they mean by that?”

Less Like:

> [Students 4 & 6] "The big idea they are missing is that evidence…you can look at data as evidence but like the thing [NOSSE Guide] says, it is an interpretation. So you have to have that data, and that data has to be used to prove something or to claim something, or answer some type of question."

Often during the NOSSE Exemplar sessions, Tracy would place a student's response, give her reason for the placement of that response, then ask me for my interpretation (as was the case with Student 3). In these cases, I would refrain from providing my interpretation and instead ask Tracy what she would like to ask the student to help her be more confident of her own interpretation. Tracy's reflection on the student exemplars and the meanings they ascribed to the aspect (domain of consequence) resulted in a positive shift in her knowledge about the difference between data and evidence (further evidence for reflective link 1, Figure 4.22).

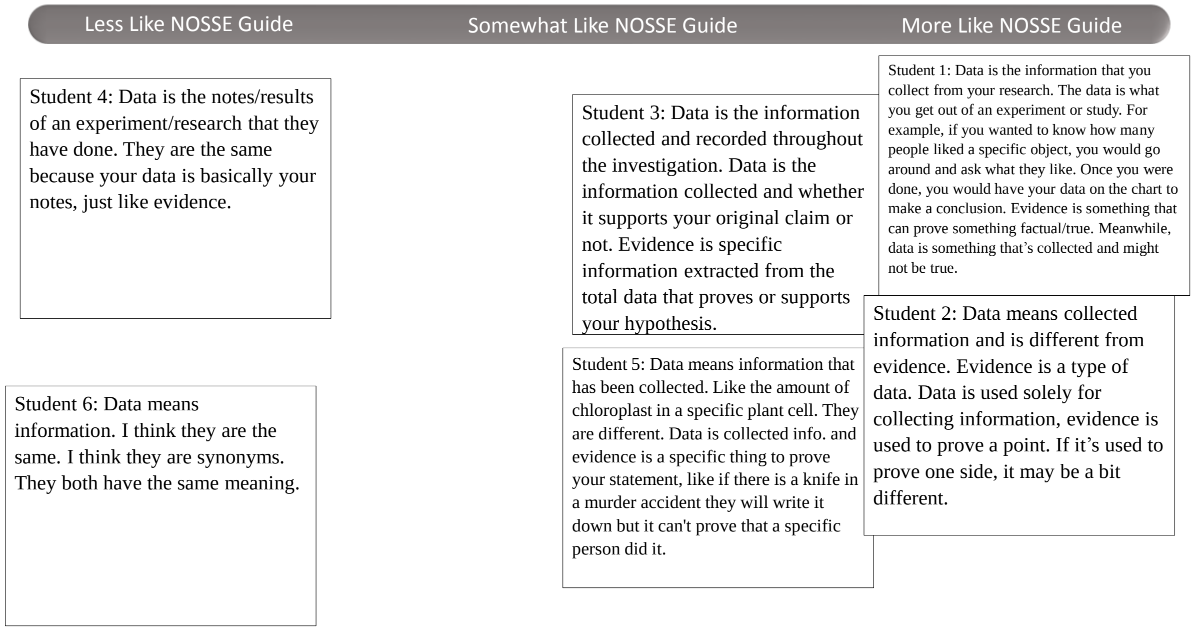

Figure 4.23. Tracy's placement of student exemplar responses to the question, "Is data the same or different from evidence? Explain your answer" (Abridged Student VNOS/VASI/VOSI Survey, question 5).

Diane

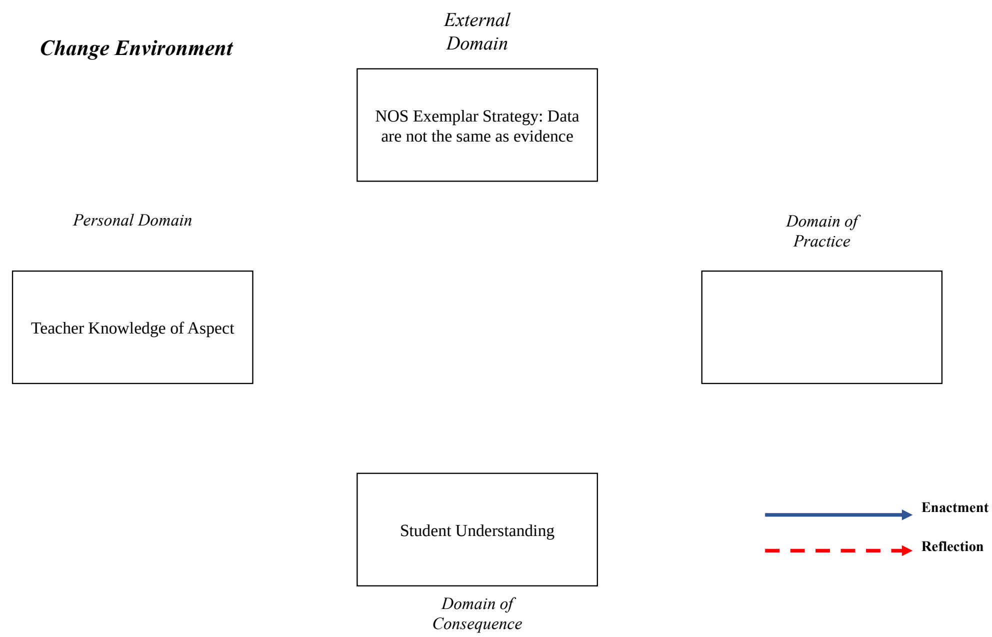

Figure 4.24. Diane's change sequence: Data are not the same as evidence (DE). There are no mechanisms (reflection and enaction) connecting domains because no changes within domains were observed for this aspect.

Diane examined the NOSSE Guide for the difference between data and evidence, but while she was trying to read the guide she was interrupted multiple times by students. She seemed distracted, so I presented her with her students' group data of their responses. A total of 17 of her students had responded that data and evidence were the same (naïve view) while 26 students stated data and evidence were different. I asked her, "Which group reflects what the guide sheet says?" (NOSSE Exemplar Strategy Session 4, DE, 1/31/2017). I expected her to identify that 26 of her students held a view congruent with the explicit information in the NOSSE Guide, but she responded:

> I would say same would reflect this [points at NOSSE guide] because it is like the quote that says, '…data and evidence are not the same… data are the information gathered during an investigation, but the interpretation of data is what supports

> evidence. So to me it's like they've got them as two separate things, entities, but, <u>they are still one without the other</u>, [emphasis added] so I feel like…I'm surprised at the answers because I think there was probably, it was probably confusing because when you read this [NOSSE Guide] it makes sense that they are not the same, but then one establishes the other. And so it is kind of, I don't know, a tricky question. I guess you'd have to ask the student, 'what do you think? what did this mean to you?' I feel like they are interpreting it a little bit differently.

In her VOSI-270 pre-assessment follow-up interview (11/29/16) regarding whether data and evidence were different, she had said "I think [they are] different. Data can take on many different levels. It may be a reading. Evidence is going to be the same data produced several times getting the same result every time." While she recognized data and evidence were different, her reasoning was erroneous and reflected a naïve view of this NOS aspect. Diane's statement above was contradictory and indicated that, despite reading the NOSSE Guide, she was firmly holding on to her own naïve view she expressed in our interview prior to the start of the study.

Diane's naïve view was also apparent in her placement of Student 6's exemplar card. Student 6's response reflected a more expert view. However, Diane's initial placement was near "somewhat like" and the following dialogue ensued:

> Researcher: You are looking at student 6 right now.
>
> Diane: Yes, and I'm putting it "somewhat like" and I feel like they're good, it is different from evidence, but then they get to data is a result and evidence helps you back that, that's kind of way out there so I felt like they were going this is

what data is, graphs can be used, so it was like they started in the right place but ended in the wrong place.

Researcher: What do you think that student would have had to say for you to move it to more like the standards documents [NOSSE Guide]?

Diane: Changing, where it says data is a result but evidence helps you back your data, so it's like this last part of the thing where it says it's, data is information gathered during an investigation that helps support it, so it's like good, evidence helps you…it's like the same thing but it's the way he worded it. I think if the wording was different I would move it. And I would probably even do this, so that it is somewhat like it meaning…I feel like they have the right idea, their wording is just throws off the clarity of it. Does that make sense? So it's not that it is way out there, it is just the wording of it.

In addition to Student 6, Diane placed students 2, 5, 6 and 3 as "somewhat like." She placed students' 1 and 4 as "more like" (Figure 4.25). Her rationale for these placements were:

More like:

[Student 1]: That one is great. So it wrapped [data and evidence] in the same blanket but yet it is showing how they are different. I'm actually going to put that one over here [more like].

[Student 4]: I like this one. I put this one in more like the standards. He's got, it says data is being investigated or collected. It's different from evidence because, and I like that it says data is collected and evidence collected to support a claim based on data. So I think that is a little bit more like what the standard is asking for.

Somewhat Like:

[Student 2]: Data is the same…both data and evidence show you how…see? This one, even though it doesn't go right here, I still feel like they have an idea. Even though it says data is the same as evidence, which the standards says it is not, I still feel like if they understand, you know, they may not be exactly the same, but they are saying it is the same so that's why I'm going to put it in the middle and not more like the standards because it is going closer.

[Student 5]: Um, I'm actually going to put this one in the middle. Started out good but it says a set of data might disprove a hypothesis or it might be irrelevant. So I don't feel like the student understands yes, it may do that, but they didn't really reference back to evidence.

[Student 3]: Even though this one says that data is the same as evidence, I like that because even though it says data is not the same as evidence, they go hand and hand. One, I feel like, is part of the other, or helps establish the other. So even where he says that data is the same, even though this goes against what the standards are saying, I'd have to put it over here. It says they are both used to make a final…says that they are not the same thing but that they are both used interchangeably so because he says data is not the same, and because of the wording again, I'm putting it here, closer to somewhat like, a little bit above it and really only because of…if you took out that one sentence.

When Diane placed Student 3 "somewhat like" despite the response indicating that data and evidence were the same (naïve view) I pursued her thinking further. I asked her about the "one sentence" and the following dialogue ensued:

Diane: The sentence that data is the same as evidence, I felt like this particular person, it doesn't necessarily go with this [NOSSE Guide] but they understood what…

Researcher: When they said "they are both used to make a final statement" I'm trying to think, or could you help me think of an example. [Interrupted by student] So this one, I'm trying to think of an example. Can you think of an example that a student could give about how data was used to support the claim or how evidence was used to support a claim. Can you think of an example? To help clarify that?

Diane: [long pause, interruptions by students]

Researcher: The example.

Diane: Well, um, I'm thinking something concrete for data. Like, how many people have gotten sick after being exposed to something to specific. We've got our data. But then that data can concludes, this is evidence, that this…

Researcher: Keep going with that thought.

Diane: Here's the data, the concrete data, the information to prove this claim, which is also evidence, like here's the evidence that proves it. That's why I say that even though it says that they are two different things, they go hand in hand.

Researcher: Why do you think it's important in the standards to say that they are different? What would be the purpose in that?

Diane: Because not all are the same. Like all, not all things fit into one box. You are going to come across some things that wouldn't necessarily fit in to that.

Researcher: What happens between data and evidence?

Diane: Data can change.

Researcher: Meaning?

Diane: Depending on…just from a classroom perspective, data can change based on a number of different factors. So, like I did a blood typing lab the other day and a real one and I was so excited but one of the serums had not been refrigerated so I was getting some strange results. You can perform that every single time and it would come out completely different. But the data can also change depending on what's going on or, do you know what I mean? By students, blood, there were other factors that were involved in it. Data can change therefore, evidence is going to be when it is repeated, you get the same thing.

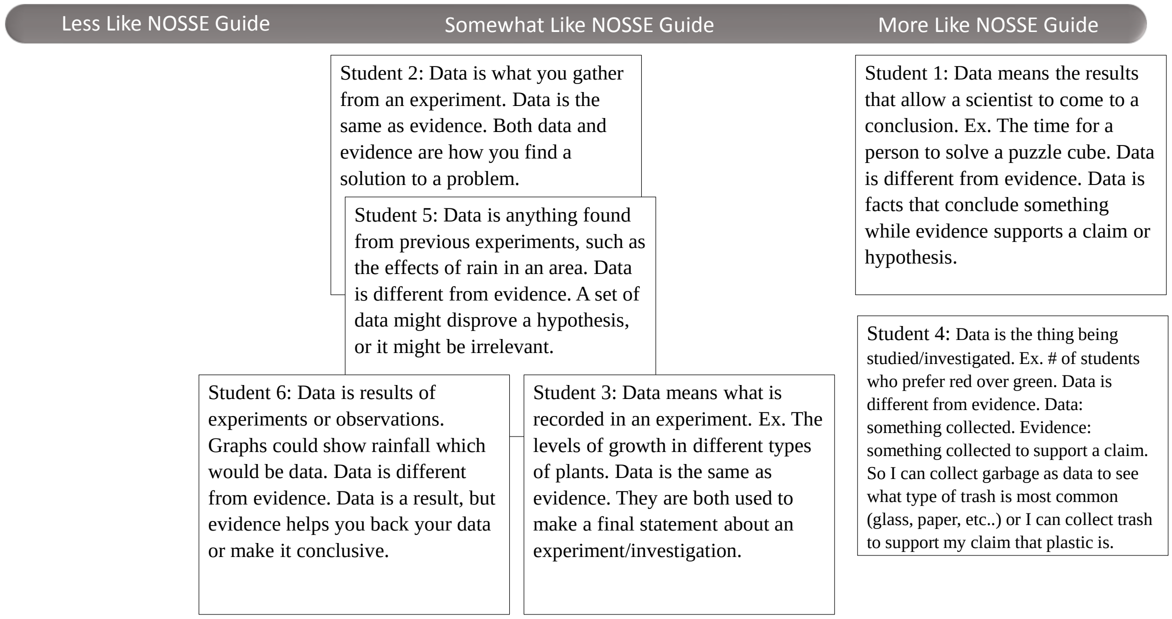

Figure 4.25. Diane's placement of student exemplar responses to the question, "Is data the same or different from evidence? Explain your answer" (Abridged Student VNOS/VASI/VOSI Survey, question 5).

Diane's reflection on the NOSSE Guide and student exemplars did not result in shifts in her knowledge about the difference between data and evidence, or any observed changes in the domain of consequence or domain of practice (Figure 4.24).

Intentions to Integrate

Each teacher completed the Intention to Integrate Nature of Science Questionnaire and pre-and post-scores for each factor were averaged across items within each factor. These factor averages were compared pre to post to indicate any changes in teacher participants intentions to integrate NOS instruction (domain of practice). (Table 4.8). After completing the NOSSE Exemplar Strategy, Tracy and Diane both had high scores for readiness, indicating they perceived themselves as more ready to integrate NOS in their classroom practice. Their scores increased on the utility factor, which indicated they perceived that integrating NOS in their classroom practice would be useful for their students. Tracy's score increased by 1.1 Likert Scale points and Diane's score increased by 3 Likert Scale points.

As for feeling pressure to integrate NOS, Tracy's score decreased, indicating she did not feel pressure from her school administrators or fellow science teachers to integrate NOS into her classroom instruction. Diane's score, however, did increase for this variable, indicating she felt that others in her change environment expected her to integrate NOS in her classroom instruction. This was evident for the pressure factor as well as the expectations factor. Both participants' scores for the control factor increased, indicating they believed they could control factors important for integrating NOS. Both teachers perceived instructional outcomes such as students easily understanding science topics and eliminating students' misconceptions about NOS as important, with both teachers scores increasing to the highest possible score (Likert Score = 7) after engaging in the NOSSE Exemplar Strategy. Attitudes toward NOS did not change much for either teacher after engaging in the strategy.

Table 4.8

Average Scores for Each Factor Regarding Intentions to Integrate Nature of Science

	Participant					
	Tracy			Diane		
Variable	PRE	POST	Change	PRE	POST	Change
Readiness	5.25	6.25	+1.0	7.00	7.0	0.0
Utility	4.90	6.00	+1.1	4.00	7.0	+3.0
Pressure	3.50	1.00	-2.5	4.50	7.0	+2.5
Control	2.50	4.00	+1.5	1.50	7.0	+5.5
Outcomes	6.00	7.00	+1.0	6.75	7.0	+.25
Expectations	4.00	1.00	-3.0	4.00	7.0	+3.0
Attitude	6.60	6.00	-.60	5.60	6.9	+1.3

Discussion

The purpose of this study was to examine the influence of the NOSSE Exemplar Strategy on inservice teacher professional growth for NOS and SI conceptions and practices. Multiple sources of data were collected to determine how and to what extent using an ostensive ER NOS strategy promoted reflection, and subsequently teacher professional growth for NOS and SI.

Results indicated that using students' exemplar responses promoted teacher reflection, resulting in positive changes for NOS and SI conceptions and intentions to integrate NOS in classroom instruction. After completing the NOSSE Exemplar Strategy, Tracy and Diane self-reported they felt more ready to integrate NOS in their classroom instruction. They also viewed NOS as more useful for their students. The use of ostensive examples to promote reflection may explain the observed changes among IMTPG domains. Teachers were engaged in thinking about NOS and SI from their students' perspectives, leading them to consider how NOS and SI ideas would be useful for students or how they could be included in their classroom instruction. Based on classroom observations and follow-up interviews, however, there was no indication either teacher included NOS or SI aspects during classroom instruction after the intervention.

The ER NOS intervention facilitated changes in teachers' NOS and SI conceptions (personal domain), but this was not sufficient to enable the transfer of this knowledge into their classroom practice (domain of practice). This was similar to what has been reported for other ER NOS interventions used to promote teacher professional growth (Akerson, et al., 2017; Wabeh & Abd-El-Khalick 2014; See Chapter 2). However, there was one instance when Tracy identified that she could explicitly include an aspect of SI in her instruction by using ConcepTests (domain of practice). This result is promising because one variable found to constrain whether a teacher includes NOS in their classroom practice is the lack of resources and means to assess students' NOS understandings (Abd-El-Khalick & Lederman, 2000). ConcepTests may be a resource teachers could develop and use to include ER NOS and SI instruction in their classroom instruction.

Though they both engaged in the NOSSE Exemplar Strategy, Tracy and Diane struggled to develop informed views of NOS and SI across all aspects. This was particularly evident with Diane holding tightly to her mixed view for the difference between data and evidence. Despite reflecting on explicit information in the NOSSE Guide and student exemplars that clearly delineated that data and evidence were different, Diane continued to see data and evidence as more similar than different. This result is similar to what was found by Kattoula (2008) when a particular case study revealed that "NOS conceptions are very much attached to what the learner already intuitively knows/believes" (p. 182). In a similar fashion, Tracy showed no shifts in growth for recognizing that observations and inferences were different.

Implications for Research and Practice

In retrospect, I could have continued to ask each teacher questions that directed them back to the NOSSE Guide to facilitate deeper reflection if they continued to hold mixed or naïve views. However, allowing participants to place exemplar cards and justify the placement with information contrary to the NOSSE Guides provided me with valuable insight into the teachers' alternative NOS and SI conceptions. For example, Diane's justification of student exemplar placements along the continuum revealed that she held on to her pre-assessment VNOS views that evidence is "the same data produced several times getting the same result every time." This is similar to findings from research about how preservice teachers perceive the need to repeat investigations over and over until the same results are observed (Schwartz, 2014).

By probing teachers' alternative conceptions, the NOSSE Exemplar strategy may be a valuable formative assessment tool for professional development leaders. Diane's reasoning process for her placement of exemplar cards was a valuable assessment of this teacher's understanding. It was clear that despite receiving explicit information in the NOSSE Guide and reflecting on exemplars, she was holding on to the erroneous idea that data and evidence are the same. Much like follow-up interviews for the VNOS and VOSI assessments, the NOSSE Exemplar Strategy can reveal teachers' misconceptions and enable professional development leaders to gauge teacher learning. This can be done *throughout*, not just before and after the professional development experience, helping science teacher educators target teachers' misconceptions for NOS and SI with more specificity as teachers engage in professional development. Future research could evaluate the effectiveness of the NOSSE Exemplar Strategy as a type of formative assessment tool.

The current study provided evidence that the NOSSE Exemplar Strategy has potential to promote teacher professional growth for NOS and SI. It is not feasible to scale-up the current strategy with more teachers because one-on-one professional development sessions are time and resource intensive. It is possible, however, that informative conversations like the one that occurred between the researcher and Diane could occur when using the NOSSE Exemplar Strategy within the context of lesson study. Lesson study provides teachers with opportunities to collaboratively plan, teach, and reflect on their practice (Stigler & Hiebert, 1999).

A recent study by Akerson, et al., (2017) explored how to facilitate the transfer of NOS knowledge into teaching practice through the use of lesson study. In this particular lesson study, preservice teachers worked together to design a lesson that included explicit NOS objectives by modifying existing curricula. Results showed that teachers were able to provide feedback to other teachers after the lesson was taught, but they were unable to incorporate this feedback into their *own* teaching of the lesson. These were preservice teachers completing their teaching practicum and their struggle to translate NOS knowledge into practice should not be a surprise as “PCK usually develops as a result of extensive and extended experiences in teaching a certain topic (Abd-El-Khalick & Lederman, 2000, p. 693). Lesson study that incorporates the NOSSE Exemplar Strategy in the context of inservice teacher professional learning communities would provide more experienced teachers the support needed to develop lessons and resources (e.g., ConcepTests) to effectively integrate ER NOS instruction in their classrooms.

Study Limitations

This was an exploratory case study used to examine a novel ER NOS intervention. The results of this study are not generalizable to participants and settings outside the context of this study. In addition, despite both teachers having a supportive change environment, each struggled to meet for more than 30 minutes, five times over the course of the semester. In many instances, the one-on-one professional development sessions were interrupted by students and staff, and some had to be rescheduled because the teacher was asked to cover a class or work with students or the teacher changed their plans due to testing or pacing guides. Barriers to implementing newly acquired pedagogical strategies include time constraints and mandated pacing guides (Buczynski & Hanson, 2010). Therefore, the NOSSE Exemplar strategy may have better results in professional development settings with dedicated hours.

Conclusion

During the first one on one professional development session, Diane told me “the [student] data to me is super interesting” (NOSSE Exemplar Strategy Session 1, NSM, 12/20/2016). When asked during the last session whether she would be interested in seeing more student data, she said, “Yeah! Yeah! I’m interested in what they say, it’s good. It’s really good” (NOSSE Exemplar Strategy Session 4, DE, 2/3/2017). Both teachers gave up valuable planning time to engage in the strategy. They were sometimes surprised at the sophistication of their students’ responses while at other times they were disappointed in the lack of understanding an exemplar represented.

The NOSSE Exemplar Strategy gave teachers the opportunity to examine NOS and SI conceptions through the eyes of their students. In this regard, using ostensive exemplars was a means for teachers to assess their students’ thinking about NOS and SI. This enabled the teachers to reflect on their own understandings and begin to think how these constructs could be included in classroom instruction. While teachers were not observed transferring their knowledge of NOS and SI into their instruction as part of this study, the use of students’ thinking in the development of teaching resources, such as ConcepTests, may provide a means for teachers to develop NOS PCK and include ER NOS and SI instruction in K-12 science classrooms.

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APPENDICES

APPENDIX 4.A

NOSSE GUIDES

Nature of Science for Science Education GUIDE
NOS Subdomain: Science Shares Methods but No Single Step-Wise Plan

Guiding Question: *How does the notion of a single, step-wise scientific method distort how science actually works?*

Summary: The Scientific Method is an oversimplified representation of what is really a rich, complex, and unpredictable process. The linear, stepwise representation of the process of science is simplified, but it does get at least one thing right. It captures the core logic of science: testing ideas with evidence. However, this version of the scientific method is so simplified and rigid that it fails to accurately portray how real science works. It more accurately describes how science is summarized *after the fact*— in textbooks and journal articles — than how science is actually done.[1]

What do science standards documents say about this NOS subdomain?

Next Generation Science Standards
Scientific Investigations Use a Variety of Methods

- Scientific investigations use a variety of methods, tools, and techniques to revise and produce new knowledge

What have nature of science experts said about this subdomain?

School science often looks like the scientific method because of an over reliance on experimental design. Clearly, there are other ways that scientists perform investigations such as observing natural phenomena. The field of astronomy relies heavily on ways of gathering data, drawing inferences, and developing scientific knowledge that do not follow "the scientific method", with descriptive and correlational research as two of the more prominent examples. In general, "scientists use different kinds of investigations depending on the questions they are trying to answer" (NRC, 2000, p. 20). This is supported by The Framework for K-12 Science Education (NRC, 2011) that states that "students should have the opportunity to plan and carry out several different kinds of investigations. . ." (p. 61), including both "laboratory experiments" and "field observations." [2]

Sources: Directly from: [1]http://undsci.berkeley.edu/article/howscienceworks_01; [2]J. Lederman et al., 2014; [3]Ten Myths of Science, McComas, 1998

Nature of Science for Science Education GUIDE
NOS Subdomains: Observations & Inferences; Creativity is Vital

Guiding Question(s): How are observations and inferences different? In what sense is scientific knowledge the product of human inference, imagination, and creativity?

Summary: Observations are different from inferences. Observations are descriptive statements about natural phenomena that are "directly" accessible to the senses (or extensions of the senses) and about which several observers can reach agreement with relative ease. For example, objects released above ground level tend to fall and hit the ground. By contrast, inferences are statements about phenomena that are not "directly" accessible to the senses (atoms, genes/DNA, magnetic fields, etc...) For example, objects tend to fall to the ground because of gravity. The notion of gravity is inferential in the sense that it can only be accessed and/or measured through its manifestations or effects.[1] …scientists approach and solve problems with imagination, creativity, prior knowledge and perseverance. These, of course, are the same methods used by all problem solvers.[3]

What do science standards documents say about this NOS subdomain?

Next Generation Science Standards
Science as a Human Endeavor
- Scientific knowledge is a result of human endeavor, imagination, and creativity
- Scientists' backgrounds, theoretical commitments, and fields of endeavor influence the nature of their findings
- Scientists rely on human qualities such as persistence, precisions, reasoning, logic, imagination and creativity

Teachers Association Position Statements
- Creativity is a vital, yet personal, ingredient in the production of scientific knowledge (NSTA).

What have nature of science experts said about this subdomain?

Although scientific knowledge is empirically-based, it nevertheless involves human imagination and creativity. Science involves the invention of explanations and this requires a great deal of creativity by scientists. This aspect of science, coupled with its inferential nature, entails that scientific concepts, such as atoms, black holes, and species, are functional theoretical models rather than faithful copies of reality.

Scientists, through their selection of problems and methods for investigation, would certainly agree that their work is creative. Even the spark of inspiration that leads from facts to conclusions is an immensely creative act. The knowledge generation process in science is as creative as anything in the arts, a point that would be made clearer to students who examine process as well as content. Unfortunately, the average student is more likely to describe science as a dry set of facts and conclusions rather than a dynamic and exciting process that leads to new knowledge. In our quest to teach students what has already been discovered, we typically fail to provide sufficient insights into the true and *creative* NOS exploration. Some studies have shown that otherwise bright students reject science as a career choice simply because they have had no opportunity to see the creativity involved.[2]

Sources: [1]Directly from Project ICAN https://science.iit.edu/mathematics-science-education/resources/lederman-depository/what-nature-science; [2]*Keys to Teaching NOS* McComas, 2004; [3]Ten Myths of Science, McComas, 1998 , and [4]*Teaching About Evolution and the Nature of Science* 1998; NGSS Lead States, 2013, Appendix H; NSTA Nature of Science Position Statement, 2000;

Nature of Science for Science Education GUIDE

NOS Subdomain: Scientific Knowledge is Tentative, Durable, & Self-Correcting

Guiding Question: In what sense is scientific knowledge tentative? In what sense is it durable?[7]

Summary: Scientific knowledge is never absolute or certain. This knowledge, including "facts," theories, and laws, is tentative and subject to change. Scientific knowledge is never 100% certain (cannot be proven) **but** scientific ideas that are supported by large amounts of evidence are accepted by the scientific community until new information, discoveries, and technologies lead scientists to change, expand, and/or refine scientific knowledge. Scientific claims change as new evidence, made possible through advances in theory and technology, is examined in the context of existing theories or laws, or as old evidence is reinterpreted in the light of new theoretical advances or shifts in the directions of established research programs.[1] We can have confidence that scientific conclusions formed using the inquiry process will be long lasting or durable because of the rigorous, self-correcting nature of the scientific process and the requirement that conclusions are agreed to by the scientific community.[2]

What do science standards documents say about this NOS subdomain?

Next Generation Science Standards

Scientific Knowledge is Open to Revision in Light of New Evidence

- Most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.
- Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation.
- Science knowledge has a history that includes the refinement of, and changes to, theories, ideas, and beliefs over time.
- The certainty and durability of science findings varies.

Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena

- A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that has been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence.

National Science Teachers Association NOS Position Statement

- Scientific knowledge is simultaneously reliable and tentative. Having confidence in scientific knowledge is reasonable while realizing that such knowledge may be abandoned or modified in light of new evidence or reconceptualization of prior evidence and knowledge.
- The history of science reveals both evolutionary and revolutionary changes. With new evidence and interpretation, old ideas are replaced or supplemented by newer ones.

What have nature of science experts said about this subdomain?

Teaching About Evolution and the Nature of Science:

"We talk about 'believing' in evolution, but that's not necessarily the right word. We accept evolution as the best scientific explanation for a lot of observations about fossils and biochemistry and evolutionary changes we can actually see, like how bacteria become resistant to certain medicines. That's why people accepted the idea that the earth goes around the sun because it accounted for many different observations that we make. In science, when a better explanation comes around, it replaces earlier ones. "Does that mean that evolution will be replaced by a better theory some day?" asks Karen. "It's not likely. Not all old theories are replaced, and evolution has been tested and has a lot of evidence to support it. The point is that doing science requires being willing to refine our theories to be consistent with new information."[4]

Sources: [1]Project ICAN https://science.iit.edu/mathematics-science-education/resources/lederman-depository/what-nature-science; [2]*Keys to Teaching NOS* McComas, 2004; [3]Lederman et al. 2002, and [4]*Teaching About Evolution and the Nature of Science* 1998; [5]NGSS Lead States, 2013; [6]NSTA Position Statement on NOS, 2000, http://www.nsta.org/about/positions/natureofscience.aspx [7]Questions rather than tenets, Clough, 2007

Nature of Science for Science Education GUIDE
SI Aspect: Data & Evidence

Guiding Question: How are data and evidence different? How are they the same?

Summary: Data and evidence serve different purposes in a scientific investigation. Data are observations gathered by the scientist during the course of the investigation, and they can take various forms (e.g., numbers, descriptions, photographs, audio, physical samples, etc.). Evidence, by contrast, is a product of data analysis procedures and subsequent interpretation, and is directly tied to a specific question and a related claim. Observations of the orbit of Mars around the sun, in and of themselves, are, simply put, an example of data. When these observations are made in conjunction with an attempt to determine the validity of Einstein's General Theory of Relativity, they constitute evidence in support of, or in opposition to, this claim.[5] It is necessary that students understand the distinction between data and evidence and can describe how the interpretation of data (i.e., the use of data as evidence) is a potential source of bias.[1]

What do science standards documents say about this SI aspect?

Next Generation Science Standards
Appendix F, Science Practices

- Once collected, data must be presented in a form that can reveal any patterns and relationships and that allows results to be communicated to others. Because raw data as such have little meaning, a major practice of scientists is to organize and interpret data through tabulating, graphing, or statistical analysis. Such analysis can bring out the meaning of data—and their relevance—so that they may be used as evidence. (p. 9)
- Scientific investigations produce data that must be analyzed in order to derive meaning. Because data patterns and trends are not always obvious, scientists use a range of tools—including tabulation, graphical interpretation, visualization, and statistical analysis—to identify the significant features and patterns in the data.

What have nature of science experts said about this aspect?

"…data and evidence are not the same… data are the information gathered during an investigation, but the interpretation of data as being supportive or contrary to a particular prediction or conclusion is evidence. In short, evidence is interpreted data."[1]

Sources: [1]Directly from Project ICAN https://science.iit.edu/mathematics-science-education/resources/lederman-depository/what-nature-science; [2]*Keys to Teaching NOS* McComas, 2004; [3]Lederman et al. 2002, [3]NGSS Lead States, 2013, Appendix H; TN Science Standards; NSTA Nature of Science Position Statement, 2000, [5]Lederman, et. al., 2014 (VASI)

APPENDIX 4.B

VNOS, VOSI, STEBI-B, & PERSONAL AGENCY BELIEFS ASSESSMENTS

Views of Nature of Science (VNOS D+) Questionnaire

Instructions

- Please answer each of the following questions. You can use all the space provided and the backs of the pages to answer a question.
- Some questions have more than one part. Please make sure you write answers for each part.
- There are no "right" or "wrong" answers to the following questions. I am only interested in your ideas relating to the following questions. If you have any question or need clarification please email me at XXXX@mtmail.mtsu.edu

1. What is science?

2. What makes science (or a scientific discipline such as physics, biology, etc.) different from other subject/disciplines (art, history, philosophy, etc.)?

3. Scientists produce scientific knowledge. Do you think this knowledge may change in the future? Explain your answer and give an example.

4. (a) How do scientists know that dinosaurs really existed? Explain your answer.

   (b) How certain are scientists about the way dinosaurs looked? Explain your answer.

   (c) Scientists agree that about 65 millions of years ago the dinosaurs became extinct. However, scientists disagree about what caused this to happen. Why do you think they disagree even though they all have the same information?

   (d) If a scientist wants to persuade other scientists of their theory of dinosaur extinction, what do they have to do to convince them?

   Explain your answer.
5. In order to predict the weather, weather persons collect different types of

information. Often they produce computer models of different weather patterns.
(a) Do you think weather persons are certain (sure) about the computer models of the weather patterns?

(b) Why or why not?

6. The model of the inside of the Earth shows that the Earth is made up of layers called the crust, upper mantle, mantle, outer core and the inner core. Does the model of the layers of the Earth *exactly* represent how the inside of the Earth looks? Explain your answer.

7. Scientists try to find answers to their questions by doing investigations / experiments. Do you think that scientists use their imaginations and creativity when they do these investigations / experiments?
(a) If **NO**, explain why.
(b) If **YES**, in what part(s) of their investigations (planning, experimenting, making observations, analysis of data, interpretation, reporting results, etc.) do you think they use their imagination and creativity? Give examples if you can.

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

9. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change? Explain and give an example.

10. Is there a relationship between science, society, and cultural values? If so, how? If not, why not? Explain and provide example

VOSI-270

Name: ________________ Date: __________________

- You have had years of experiences with science, in the classroom and in real life. This survey asks you to think about science and describe your ideas. There are no right or wrong answers, as these are simply your ideas at this time. Please respond as completely as you can. You can use as much space as you need.

- Some questions have more than one part. Please make sure you write your answers to each part.

- This survey is NOT an evaluation of you. You will not be graded or judged based on your answers. If you need clarification please contact me at jp4k@mtmail.mtsu.edu

-

1. What types of activities do scientists (e.g., biologists, chemists, physicists, earth scientists) do to learn about the natural world? Discuss how scientists (biologists, chemists, earth scientists) do their work.

2. A lot of science relies on terminology. We'd like to know how you understand and use some of common terms in science.

(a) What do you think a scientific experiment is? Give an example to support your answer

(b) 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.

(c) What does the word "data" mean in science?

(d) Do you think "data" the same or different from "evidence" ? Explain.

3. Models are widely used in science. What is a scientific model? Describe and give an example.

A scientific model is….

Give an example of a model:

4. A person interested in animals looked at hundreds of different types of animals who eat either meat or plants. He noticed that those animals who eat similar types of food tend to have similar teeth structures. For example, he noticed that meat eaters, such as lions and coyotes, tend to have teeth that are sharp and jagged. They have large canines and large, sharp molars. He also noticed that plant eaters, such as deer and horses, have smaller or no canines and broad, lumpy molars. He concluded that there is a relationship between teeth structure and food source in the animals.

(a) Do you consider this person's investigation to be an experiment? Please explain why or why not.
(b) Do you consider this person's investigation to be scientific? Please explain why or why not by describing what it means to do something "scientifically."

This investigation is / is not (circle one) scientific because….

5. The "scientific method" is often described as involving the steps of making a hypothesis, identifying variables (dependent/independent), designing an experiment, collecting data, reporting results. Do you agree that to do good science, scientists must follow the scientific method?

______YES, scientists must follow the scientific method

_______NO, there are many scientific methods

- If YES (you think all scientific investigations must follow a standard set of steps or method), describe why scientists must follow this method.
- If NO (you think there are multiple scientific methods), explain how the methods differ and how they can still be considered scientific.

6. Scientists do lots of investigations and then share their findings with other people. They publish their work in scientific journals. They speak about their work at meetings and even on TV.
   (a) How do scientists know when they are ready to make their research results public? What kind of information do they need in order to convince others that their findings are valid (believable)?
   (b) Do you think all types of scientists have the same requirements as you stated in (a) for justifying and accepting scientific claims? Explain and give examples.

7. Scientists sometimes encounter inconsistent findings (*anomalous* information).

(a) How are anomalies identified in science? (i.e. What is considered "inconsistent" in scientific research?) Provide an example, if possible.
(b) What do you think scientists do when they find an anomaly?
(c) Do you think all scientists identify and handle anomalous information this same way? Why or why not?
(d) How do *students* typically identify and handle anomalies (inconsistent data) in a science classroom? What do you think is the motivation for students to do this?

(e) Do you think students and scientists handle anomalies in the same way?

YES / NO

For the same reasons? YES / NO

Explain your choices.

STEBI-B

Please indicate the degree to which you agree or disagree with each statement.

SA= Strongly Agree
A= Agree
UN=Uncertain
D= Disagree
SD= Strongly Disagree

1. When a student does better than usual in biology, it is often because the teacher exerted a little extra effort.	SA	A	UN	D	SD
2. I continually find better ways to teach biology.	SA	A	UN	D	SD
3. Even if I try very hard, I do not teach biology as well as I do most subjects.	SA	A	UN	D	SD
4. When the biology grades of students improve, it is often due to their teacher having found a more effective teaching approach.	SA	A	UN	D	SD
5. I know the steps necessary to teach biology concepts effectively.	SA	A	UN	D	SD
6. I am not very effective in monitoring biology experiments.	SA	A	UN	D	SD
7. If students are underachieving in biology, it is most likely due to ineffective biology teaching.	SA	A	UN	D	SD
8. I generally teach biology ineffectively.	SA	A	UN	D	SD
9. The inadequacy of a student's biology background can be overcome by good teaching.	SA	A	UN	D	SD
10. The low biology achievement of some students cannot generally be blamed on their teachers.	SA	A	UN	D	SD
11. When a low achieving child progresses in biology, it is usually due to extra attention given by the teacher.	SA	A	UN	D	SD
12. I understand biology concepts well enough to be effective in teaching high school biology.	SA	A	UN	D	SD
13. Increased effort in biology teaching produces little change in some students' biology achievement.	SA	A	UN	D	SD

14. The teacher is generally responsible for the achievement of students in biology.	SA	A	UN	D	SD
15. Students' achievement in biology is directly related to their teacher's effectiveness in biology teaching.	SA	A	UN	D	SD
16. If parents comment that their child is showing more interest in biology at school, it is probably due to the performance of the child's teacher.	SA	A	UN	D	SD
17. I find it difficult to explain to students why biology experiments work.	SA	A	UN	D	SD
18. I typically am able to answer students' biology questions.	SA	A	UN	D	SD
19. I wonder if I have the necessary skills to teach biology.	SA	A	UN	D	SD
20. Given a choice, I do not invite the principal to evaluate my biology teaching.	SA	A	UN	D	SD
21. When a student has difficulty in understanding a biology concept, I usually am at a loss as to how to help the student understand it better.	SA	A	UN	D	SD
22. When teaching biology, I usually welcome student questions.	SA	A	UN	D	SD
23. I do not know what to do to turn students on to science.	SA	A	UN	D	SD

Context Beliefs About Teaching Science Beliefs about Teaching Science

Directions: Suppose your goal is to be the most effective science teacher possible during the next school year. Listed below are a number of school environmental support factors that may have an impact on this goal. In the first column, please indicate the degree to which you believe each factor <u>will enable you to be an effective science teacher</u>. In the second column, indicate the <u>likelihood that these factors will occur</u> (or be available to you) during the next school year. Circle the corresponding descriptor that matches your belief.

	Column 1	Column 2
Environmental Factor	The following factors would enable me to be an effective teacher SA= strongly agree; A= agree; UN = undecided; D = disagree; SD = strongly disagree	How likely is it that these factors will occur in your school? VL =very likely; SL =somewhat likely; N =neither; SU = somewhat unlikely; VU = very unlikely
1. Professional staff development on teaching (workshops, conferences, etc.)	SA A UN S SD	VL SL N SU VU
2. State and national guidelines for science education (standards and goals)	SA A UN S SD	VL SL N SU VU
3. Support from other teachers (coaching, advice, mentoring, modeling, informal discussions, etc.)	SA A UN S SD	VL SL N SU VU
4. Team planning time with other teachers	SA A UN S SD	VL SL N SU VU
5. Hands-on science kits (activities and equipment)	SA A UN S SD	VL SL N SU VU
6. Community involvement (civic, business, etc.)	SA A UN S SD	VL SL N SU VU
7. Increased funding	SA A UN S SD	VL SL N SU VU
8. Extended class period length (e.g., block scheduling)	SA A UN S SD	VL SL N SU VU
9. Planning time	SA A UN S SD	VL SL N SU VU
10. Permanent science equipment (microscopes, glassware, etc.)	SA A UN S SD	VL SL N SU VU
11. Classroom physical environment (room size, proper furniture, sinks, etc.)	SA A UN S SD	VL SL N SU VU
12. Adoption of an official school science curriculum (goals, objectives, topics, etc.)	SA A UN S SD	VL SL N SU VU
13. Expendable science supplies (paper, chemicals)	SA A UN S SD	VL SL N SU VU
14. Support from administrators	SA A UN S SD	VL SL N SU VU

15. Science curriculum materials (textbooks, lab manuals, activity books, etc.)	SA A UN S SD	VL SL N SU VU
16. Technology (computers, software, Internet)	SA A UN S SD	VL SL N SU VU
17. Parental involvement	SA A UN S SD	VL SL N SU VU
18. An increase in students' academic abilities	SA A UN S SD	VL SL N SU VU
19. Involvement of the state board of education	SA A UN S SD	VL SL N SU VU
20. A decrease in your course teaching load	SA A UN S SD	VL SL N SU VU
21. A reduction in the amount of content you are required to teach	SA A UN S SD	VL SL N SU VU
22. Reduced class size (number of pupils)	SA A UN S SD	VL SL N SU VU
23. Involvement of scientists	SA A UN S SD	VL SL N SU VU
24. Involvement of university professors	SA A UN S SD	VL SL N SU VU
25. Classroom assessment strategies	SA A UN S SD	VL SL N SU VU
26. Teacher input an decision making	SA A UN S SD	VL SL N SU VU

(Lumpe, Handy, & Czerniak, 2000)

APPENDIX 4.C

Student VNOS/VOSI/VASI Surveys

Name: ___________________________________

Date: ____________________________________

Views of Scientific Inquiry and the Nature of Scientific Knowledge Questionnaire

- *The following questions are asking for your views related to science and scientific investigations. There are no right or wrong answers.*
- *Please answer each of the following questions. You can use all the space provided to answer a question and continue on the back of the pages if necessary.*

1. What is science?

2. How do scientists decide what and how to investigate? Describe all the factors you think influence the work of scientists. Be as specific as possible.

3. Do you think that scientific investigations can follow more than one method? (circle one)

   YES **NO**

   If no, please explain why there is only one way to conduct a scientific investigation.

   If yes, please describe two investigations that follow different methods, and explain how the methods differ and how they can still be considered scientific.

4. What does the word "data" mean in science? Give an example.
5. Is "data" the same or different from "evidence"? Circle one.

   SAME **DIFFERENT**

   Explain your answer.

6. Scientists produce scientific knowledge. Do you think this knowledge may change in the future? Explain your answer and give an example.
7. How do scientists know that dinosaurs really existed? Explain your answer.

8. How certain are scientists about the way dinosaurs looked? Explain your answer.

9. The model of the inside of the Earth shows that the Earth is made up of layers called the crust, upper mantle, mantle, outer core, and inner core. Does the model of the layers of the Earth *exactly* represent how the inside of the Earth looks? Explain your answer.

10. Two students are asked if scientific investigations must always begin with a scientific question. One of the students says "yes" while the other says "no." Whom do you agree with and why?

11. Two teams of scientists are walking to their lab one day and they saw a car pulled over with a flat tire. They all asked, "Are different brands of tires more likely to get a flat?"

    Team A when back to the lab and tested various tires' performance on three types of road surfaces.

    Team B went back to the lab and tested one tire brand on three types of road surfaces.

    Explain why one team's procedure is better than the other one.

12. The data table below shows the relationship between plant growth in a week and the number of minutes of light received each day.

Minutes of light each day	Plant growth-height (cm per week)
0	25
5	20
10	15
15	10
20	5
25	0

Given this data, explain which of the following conclusions you agree with (circle one).

A. Plants grow taller with **more** sunlight.
B. Plants grow taller with **less** sunlight.
C. The growth of plants is **unrelated** to sunlight.

Explain your answer.

Are the data what you expected? Why or why not?

APPENDIX 4.D

Institutional Review Board Approval Letter

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research Compliance,
010A Sam Ingram Building,
2269 Middle Tennessee Blvd
Murfreesboro, TN 37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBN001 - EXPEDITED PROTOCOL APPROVAL NOTICE

Thursday, August 18, 2016

Investigator(s): Thomas Cheatham (PI), Grant Gardner and Leigh McNeil
Investigator(s') Email(s): *tom.cheatham@mtsu.edu; grant.gardner@mtsu.edu; leigh.mcneil@mtsu.edu*
Department: TN STEM Education Center, MTSU

Study Title: ***Promoting active learning strategies in Biology (PALS)***
Protocol ID: **16-2001 (NSF DRL-1417735)**

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU Institutional Review Board (IRB) through the **EXPEDITED** mechanism under 45 CFR 46.110 and 21 CFR 56.110 within the category *(7) Research on individual or group characteristics or behavior* A summary of the IRB action and other particulars in regard to this protocol application is tabulated as shown below:

IRB Action	APPROVED for one year	
Date of expiration	**8/4/2017**	
Sample Size	13,000 (THIRTEEN THOUSAND)	
Participant Pool	**School Teachers and their Minor Students**	
Exceptions	Permitted to subdelegate the participating teachers to conduct a few minor interventions on behalf of the investigators after the teachers have been trained in human subjects research.	
Restrictions	**(1) Mandatory informed consent, active parental consent and child assent;** **(2) The list of approved schools is in file with the Office of Compliance - more schools may be added only after IRB approval;** **(3) The participating teachers must complete the "Working With Minors" MTSU IRB training before assuming investigator responsibilities.**	
Comments	(1) The protocol is an extension of 15-009; (2) The investigators were allowed to add several schools over the last year through addendum requests. The names of the schools are not shown in this notification due to space consideration - MP 08.18.2016; (3) Jennifer Parrish was originally added to 5-009 - MP 08.18.2016	
Amendments	**Date**	**Post-approval Amendments**
	11.02.2015	"Science Teacher Efficacy Beliefs Instrument (STEBI-B)" has been reviewed and approved for use
	05/12/2016	(1) A modified child assent to accurately reflect the intervention has been approved

CHAPTER FIVE: CONCLUSION

A review of over two decades of research on ER approaches to facilitate K-12 teacher professional growth for NOS and SI confirmed that 1) using explicit and reflective approaches are effective and 2) changing teachers' NOS and SI conceptions *and* practices (NOS PCK) is extremely difficult. The purpose of this dissertation was to examine whether and how a novel ER NOS intervention, the NOSSE Exemplar Strategy, promoted teacher professional growth for NOS and SI. In both research studies, the NOSSE Exemplar Strategy promoted the most teacher growth within the teachers' personal domain, particularly in their knowledge of NOS and SI aspects. Few changes in teachers' domain of practice were observed, providing more evidence of the difficulty of developing teachers' NOS and SI PCK (Wahbeh & Abd-El-Khalick, 2014).

In order for teachers to include NOS and SI in their classroom practice, they must internalize the belief that NOS is an important learning outcome for their students. It is only then that teachers will intentionally integrate ER NOS instruction into their existing curricula (Lederman, 1999). Use of the NOSSE Exemplar Strategy resulted in some changes in teachers' intentions to integrate NOS in their classroom instruction. In both studies, teachers perceived themselves as more ready to include NOS in their future classroom instruction after completing the NOSSE Exemplar Strategy. However, only the inservice teachers in Chapter 4 perceived NOS knowledge as more useful for their students. As such, further examination of the NOSSE Exemplar Strategy in the context of inservice teacher professional development is necessary.

The NOSSE Exemplar Strategy was developed using the principles of ostention because this approach has not been explored as extensively in teacher professional development as the use of decontextualized and contextualized NOS activities or historical case studies. Exploratory in nature, both studies provided evidence that using an intervention that incorporated ostensive exemplars promoted reflection that resulted in teacher professional growth for NOS and SI. This was evident for both preservice teachers (Chapter 3) and inservice teachers (Chapter 4).

Promoting reflection through contradictory information may be a catalyst for conceptual change (Limon, 2001). As such, one explanation why exemplars were a powerful reflective tool is that teachers saw their own conceptions (both naïve and informed) reflected within particular exemplar responses. This resulted in reflection in the form of hesitation and perplexity, specifically when there was a contradiction between a naïve exemplar a teacher identified with and the expert-like view contained within the NOSSE Guides. Future studies can provide more detail about the extent and types of reflection that result from the cognitive conflict teachers experience when presented with ostensive exemplars that contradict information in the NOSSE Guides.

I developed the NOSSE Guides to make expert-like conceptions of NOS and SI aspects explicit and accessible to teachers. My work with teachers prior to this dissertation revealed that in general, teachers are completely unfamiliar with the constructs of NOS and SI despite using standards documents (e.g., NGSS, state science standards) to determine what content to include in their classroom practice. In some cases, such as in state standards documents, there is no mention of the NOS and SI aspects that guided this study. Even though NOS and SI are included in NGSS, science education researchers have argued they are inadequately described and included (Nouri & McComas, 2016). Therefore, I saw a need to scour standards documents and NOS literature for teachers to develop NOSSE Guides that K-12 teachers could use as a referent as they reflected on NOS and SI aspects. Based on the results from both studies, NOSSE Guides helped teachers access and reflect on NOS and SI aspects. Therefore, these guides may be useful tools for science teacher educators to use in teacher preparation and professional development settings.

Experts in NOS and SI education research have reiterated that reflection on NOS and SI aspects requires context:

> "We believe that developing science teachers' views of NOS would be achieved best in the context of science content courses. An explicit, reflective approach to NOS instruction embedded in the context of learning science content would not only facilitate developing science teachers' NOS views, but might go a long way in helping teachers transfer their NOS understandings into actual classroom practices" (Akerson, Abd-El-Khalick, & Lederman, 2000, p. 297).

The NOSSE Exemplar Strategy provided the opportunity for teacher-learners to experience an explicit and reflective approach to NOS instruction 'embedded in the context of learning science content' (e.g., science course or curriculum being taught) *and* in the context of students' thinking. In Chapter 3 preservice teachers reflected on exemplars of other teacher-learners and in Chapter 4 inservice teachers reflected on their own students' thinking regarding NOS and SI. In this regard, exemplars served as a modified means of formative assessment, particularly for inservice teachers. Formative assessment is defined by Popham (2008) as a "planned process in which teachers or students use assessment-based evidence to adjust what they're currently doing" (p.6). The NOSSE Exemplar Strategy served a modified means of formative assessment for the teachers because the exemplar responses provided "assessment-based evidence" that enabled teachers to adjust their thinking about NOS and SI aspects.

The VNOS, VOSI, and VASI questionnaires have been used extensively to diagnose and monitor learners' NOS and SI conceptions, usually in response to an intervention. However, using exemplar responses from these instruments as a means of formative assessment transforms these instruments into reflective tools that become "assessments for learning, not assessments of learning" (Keeley, Eberle, and Farrin, 2005, p. 3). Exemplar student responses from the VNOS, VOSI, and VASI could be used to develop resources, such as ConcepTests (Mazur, 1997), that teachers and science teacher educators can use to formatively assess their students' understandings and make adjustments accordingly.

This dissertation described teacher professional growth that occurred as a result of using the NOSSE Exemplar Strategy with preservice and inservice teachers. The search for ways to enhance teacher professional growth regarding NOS and SI is a well-established need (Chapter 1) and different approaches to research in this field are needed to better understand factors that promote teacher professional growth for NOS and SI (Chapter 2). Overall, using an ER NOS strategy that incorporated ostensive exemplars changed teachers' conceptions of NOS and SI and teachers who engaged in this strategy perceived themselves as more ready to include NOS in their classroom practice (Chapters 3 and 4). However, science standards documents and textbooks do not prominently and accurately feature NOS and SI, making it necessary for the continued development of ER NOS strategies that facilitate the translation of teachers’ NOS and SI understandings into classroom instruction.

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