Applications of the Nature of Science to Teacher Pedagogy Through the Situation of Neuroscience Within the Context of Daily Classroom Practice

Kristina Hopkins

Submitted in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy
under the executive committee
of the Graduate School of Arts and Sciences

COLUMBIA UNIVERSITY
2018

ABSTRACT

Applications of the Nature of Science to Teacher Pedagogy Through the Situation of Neuroscience Within the Context of Daily Classroom Practice

Kristina Hopkins

Educational research has established a positive influence of learning the nature of science (NOS) on teachers' practice when an explicit reflective approach to instruction is employed (Abd-El-Khalick, 2001; Abd-El-Khalick & Akerson, 2004; Akerson, Abd-El-Khalick, & Lederman, 2000; Duschl & Grandy, 2013; Lederman, 2007; Pintrich, Marx, & Boyle, 1993; Schwartz & Crawford, 2004). Additionally, research focused on the utility of teaching teachers neuroscience has indicated a positive connection between learning neuroscience in professional development settings and effective classroom practice (Dubinsky, Roehrig, & Varma, 2013; Roehrig, Michlin, Schmitt, MacNabb, & Dubinsky, 2012). Therefore, this study hypothesizes that there is an important connection between neuroscience and teachers' conceptions of the NOS, in that neuroscience can be used as a tool to better understand the complex NOS, and that this understanding has connections to classroom practice. This study presents an approach for NOS instruction that utilizes a situated approach for teaching NOS in addition to using "catalytic groups" to push forward the discussions about the potential connections that could be made between neuroscience and the NOS. The goal of this study was to explore the potential relationship between neuroscience and the NOS as a method for better understanding the complex NOS and define that relationship more clearly. Additionally, the study was designed to measure the effectiveness of the alternative design approach for situated NOS instruction. This novel design approach consisted of the use of 'catalytic groups', or small groups that met outside of class time, whose conversations guided the conceptual changes for students in the larger class setting.

A mixed-methods analysis was utilized to investigate how the 17 participants in this study interacted over the course of the four weeks, how their understandings of the NOS and their attitudes and beliefs toward integrating neuroscience and the NOS change over time into one cohesive understanding of NOS. Additionally, a case study was conducted that provided deeper insight into participant interactions during the four-week course. Evidence collected in this study included Likert surveys, open-ended reflection reports, observations, a researcher journal, and transcriptions of catalytic group settings. Using a theoretical framework of conceptual change, a number of findings were realized from the evidence collected. These findings are presented in the form of a manuscript approach to the dissertation, where each Results chapter is presented as a single, separate research paper that is appropriate for formal publication. These two separate manuscripts use conceptual change as the theoretical framework for data analysis. Chapter 4 presents the mixed-methods analysis of all 17 participants in the study and Chapter 5 presents a mixed-methods, case study approach of three participants.

Based on the evidence in Chapter 4, three major findings were realized: (1) previous exposure to the NOS may help students to apply the abstract tenets of the NOS to a scientific context, (2) the use of neuroscience as a situated approach for NOS instruction was particularly effective for areas of neuroscience most closely related to teachers' practice, and (3) added time for critical reflection and small-group discourse impacted the perceived importance of the NOS on daily classroom practice. The three findings provide evidence for a meaningful re-design of the novel instructional approach used in this study for further implementation in NOS instruction, with an emphasis on utilizing small-group discussion settings for students to reflect on their changing understandings of NOS in relation to teacher pedagogy.

Based on the evidence in Chapter 5, three main findings are reported: (1) the degree of appropriateness of neuroscience for contextualized NOS instruction may be varied based on students' perceived intelligibility of neuroscience, (2) when context-specific NOS instruction is utilized, it is imperative that students connect the specific context used for instruction to their own scientific knowledge and experiences, and (3) when students are learning the NOS, those learning opportunities must have perceived value and relevance to the professional development of students. The findings from this study provide evidence of the usefulness of integrating neuroscience and the NOS in the quest to better understand how students comprehend the nature of the scientific discipline. In this study, neuroscience was particularly useful because of its character as a 'contemporary science story', where the tenets of NOS are explicit and easy to see. Areas of future research are also explored, with suggestions on the use of neuroscience to teach the complex NOS.

Three common themes describe the findings from each of the Results chapters that comprise this study. First, neuroscience can prove as a useful scientific context for NOS instruction even when students are not necessarily familiar with neuroscience content. However, this usefulness depends on students' ability to connect neuroscience to classroom practice and/or to their own science disciplinary focus. Second, critical reflection proved to be an important aspect of NOS instruction, as it allowed students to reflect on their own understandings of the NOS with a focus on how those understandings have changed over time. Last, the catalytic groups that define the alternative model for NOS instruction that was used in this study positively impacted NOS learning. These groups impacted students' ability to synthesize neuroscience with the NOS into a cohesive understanding of the NOS at a general level. These findings leave a variety of implications for future NOS instruction in addition to suggestions for the future use of the instructional approach presented in this study. Those implications include the use of more catalytic groups for NOS instruction, where all students are engaged in small-group discussions that inform future NOS instruction, and more targeted metacognitive strategies for NOS instruction, where specific strategies are employed to allow all learners to develop a ‘deep processing’ orientation toward the NOS.

Table of Contents

List of Figures

List of Tables

Acknowledgements

I would like to thank my advisors at Teachers College, Columbia University for their support that made this novel approach to instruction come to life. A special thank you to Dr. O. Roger Anderson, whose detailed and insightful comments on this study greatly improved the manuscript. Additionally, Dr. Anderson helped me to frame the ways in which I would approach the dissertation study and gave backing to an ‘unchartered’ field of teacher education that we both believe has an unquantifiable merit in teacher preparation. I would also like to extend a special thank you to Dr. Christopher Emdin, who allowed me to use his course to facilitate this study and achieve my dream of finally integrating neuroscience and scientific philosophy. Additionally, Dr. Emdin challenged me to consider the multiple, varied perspectives of the world, which allowed me to see the great value in learning from others. Third, I would like to thank the chair of my committee, Dr. Felicia Moore Mensah, for giving me great insight on methodologies of qualitative research and organizing my committee meetings. Last, I would like to thank Dr. Andy Gordon and Dr. Bob Newton for agreeing to spend time reading my work and giving critical feedback, which allowed me to grow professionally.

Next, I would like to thank my family for the unconditional support that they have given me through this process of earning a doctoral degree. Receiving a high-level degree was tough in many ways, especially given the young age at which I have completed this task. As I navigated through identity shifts and formations, they held steady, providing me a grounding support without which I would not have succeeded. To my father, I thank you for consistently telling me, “they will love you for you who are”. He has taught me to see that the experiences you have do not define your identity, but rather are woven together, into a multi-faceted story that does not limit us to one way of being. To my mother, I thank you for your example of how to live as a strong, independent, and educated woman. You taught me very early in my life to never back down from a challenge, and that quitting is neither an option nor a resolution. To my sister, you provide an emotional connection and a light in my life in a way which no one else can give. You work hard, you are proud, and you are loyal. Lastly, I thank my gracious and loving grandmother. Your presence in my life is unforgettable. You have led a fulfilling life of patience, grace, and selflessness. I thank you for teaching me what love truly means.

Lastly, I would like to thank the participants of this study, whose thoughtful participation allowed me to gain valuable insight into this type of work. Being that this dissertation study afforded me the opportunity to navigate unchartered territory in the field of science teacher education, it was with some hesitation that participants saw an initial value in my work. Nevertheless, they navigated forward with me, and I thank each participant for their time and efforts. It was extremely rewarding to work with the participants of this study who volunteered to work with me outside of class time. I will always value the critically reflective discourses that we had as a result of this research opportunity.

Chapter 1

INTRODUCTION

Discussions on the nature of science (NOS) in science education reform documents emphasize the benefit of understanding the NOS for both students and teachers in order to gain a more holistic understanding of the scientific discipline (American Association for the Advancement of Science [AAAS], 1990, 1993; National Research Council [NRC] 1996, 2011; NGSS Lead States, 2013). More recent research related to the NOS investigates strategies that are effective for teaching it to K-12 students, in-service science teachers, and prospective science teachers. Despite decades of work in fostering the most effective strategies, there is still no consensus on one 'best' way to teach the NOS to any of these groups of people. Research in fostering pre-service teachers' (PST) and in-service teachers' (IST) understandings of the NOS has given tremendous insight into the effectiveness of an explicit, reflective approach to teaching the NOS within a scientific context (Abd-El-Khalick, 2001; Abd-El-Khalick & Lederman, 2000; Abd-El-Khalick, Bell, & Lederman 1998; Akerson, Abd-El-Khalick, & Lederman, 2000; Bell, Lederman, & Abd-El-Khalick, 2000; Irez, 2006; Koenig, Shen, and Bao, 2012; Lederman, 2007; Ryan & Ikenhead, 1992; Schwartz, Lederman, & Crawford, 2004). In addition, recent work in the domain of neuroscience in education discovered that knowing how the brain works would benefit teachers' classroom practice (Bernardon, 2013; Dubinsky, 2010; Dubinsky, Roehrig, & Varma, 2013; Roehrig, Michlin, Schmitt, MacNabb, & Dubinsky, 2012). Situating the learning of the NOS within the context of curriculum relevant examples of how neuroscience can inform curricular strategies may provide a more meaningful and engaging opportunity for pre-service and in-service teachers to learn about NOS.

Problem Statement

The current state of pre-service and in-service science teacher education does not provide a consistently productive method for teaching the NOS to prospective and in-situ educators. Despite many decades of researching the effectiveness of varying strategies for teaching the NOS to PST's, it is very rare that these teachers take their well-developed and eloquent ideas of the NOS and apply them to classroom practice. Even if pre-service and in-service teachers are provided the opportunity to apply the NOS to lesson planning and other aspects of classroom practice, many teachers end up reverting back to their previously-held and naïve views of the NOS (Akerson, Morrison, & McDuffie, 2006). This may occur because in many science education classroom settings, both pre-service and in-service teachers are generally learning the NOS in a decontextualized manner, where they discuss theories in a broad sense with very little time or activities devoted to application of the NOS to classroom practice (Abd-El-Khalick, 2001; Abd-El-Khalick *et al*., 1998; Akerson *et al*., 2000; Koenig *et al*., 2012; Schwartz & Crawford, 2004; Schwartz *et al*., 2004). Thus, there is a need for a new model of teaching the NOS to PST's and IST's, where teachers are learning NOS in a manner that coincides with the characteristics of productive professional development and allows for greater instructional time devoted to applications to classroom practice. This type of model may better streamline the process of bringing NOS into K-12 science classrooms through helping teachers adopt their developed NOS views into their practice.

Additionally, there is a call for teachers to learn more about how the neuroscience of the brain contributes to or strays from classroom teaching and learning strategies. As it stands now, teachers are not required neither to take any classes on neuroscience, despite it being the organ of learning, nor do they take many classes (if any at all) on psychology or sociology of learning. As a result, teachers' conceptions of neuroscience and how students think are largely based on 'neuromyths' that populate themselves in schools via brain-based products (Ansari, Coch, & De Smedt, 2011; Atherton & Diket, 2005; Goswami, 2006; Sylvan & Christodoulou, 2010; Willingham, 2006). Yet, current educational research has found that neuroscience is a valuable content for teachers to know and it has a positive effect on their classroom practice (Roehrig *et al*., 2012). Although the current research paradigm of educational neuroscience has not found direct and specific links of neuroscientific findings to productive teaching and learning strategies, it is beneficial for teachers to familiarize themselves with the current neuroscientific research and consistently challenge the brain-based products that come their way in educational settings. In this research objective, teachers were exposed to three items of neuroscientific research that contribute to classroom pedagogies (though I warn that this contribution is neither direct nor simple), thereby familiarizing participants with the current neuroscientific knowing's of the brain. Additionally, teachers were challenged to connect some of these findings to conceptions of the NOS, as neuroscience was the grounding scientific context for participants to develop a deeper understanding of the nature of scientific knowledge.

Significance

This research objective contributes in a very productive way to the current field of teaching NOS in science teacher education programs. It is vital that science teacher education programs continue to teach its students how scientific knowledge has developed over time. The jury is still out on a productive and consistent method for delivering NOS content that PST's and IST's can carry with them into their classroom teaching experiences. As a result, this research objective contributes to the literature as a fruitful and productive way to teach the NOS in science teacher education. Additionally, current research in science education has yet to connect neuroscience as a foundation for learning the NOS. This study describes a method that can be used to implement this type of model for teaching the NOS to pre-service and in-service science teachers. Furthermore, this research objective allows for science teachers to develop a better idea of how the brain operates in terms of learning and gives participants the opportunity to connect these scientific findings to both the NOS and classroom pedagogy.

Research Purpose

This investigation utilized a strategy that takes these specific domains of research in the NOS, educational neuroscience, science teacher education, and situated learning into account. These four research domains were used to foster a hybrid model of reform-oriented professional education for PST's and IST's enrolled in a science teacher education program. The nature of this strategy was based on inquiry-based activities in which students learned various principles of neuroscience as they relate to classroom pedagogy and inquiry learning. Additionally, this strategy utilized an explicit, reflective approach to learning the NOS that allowed for students to reflect on the NOS within the context of neuroscience in classroom practice. Additionally, neuroscience was selected as the scientific content to act as the context for which students could apply their developing yet highly theoretical understandings of the NOS to a specific scientific domain. This type of contextualized approach to teaching the NOS, in addition to utilizing an explicit and reflective approach, is necessary for elevating students' understanding of the NOS outside of a simple theoretical context. Additionally, neuroscience was selected as the grounding context for this study because of its significant presence in the field of education and in the media writ large. The goal of this investigation was to understand how this strategy unfolds over the course of four weeks and to see if there was an effect on students' ability to connect neuroscience to the NOS through inquiry learning as a classroom practice. This strategy was investigated within a teacher education course, with the overarching goal of investigating the utility of this model for the ideal professional development on the NOS.

The Research Questions

The main question of the study was "does neuroscience serve as a fruitful foundation for pre-service and in-service teachers to learn about the nature of science as it applies to classroom practice?" This research question was expanded into six research sub-questions, as follows:

1. What are the dynamics that characterize the interactions within a science teacher education intervention (a large group setting), when students discuss the integration of neuroscience with the NOS, and how do those dynamics change during a sequence of opportunities to reflect and engage in discussions about the integration of the NOS with neuroscience?
2. To what extent do pre-service and in-service teachers change their understandings of the NOS during a sequence of opportunities to reflect and engage in discussions about the integration of the NOS with neuroscience?
3. How do participants' attitudes and beliefs on the integration of neuroscience and the NOS change as they engage in the four-week teacher education intervention on neuroscience and the NOS?
4. Overall, how effective was the catalytic group function in the integration of neuroscience and the NOS during the 4-week teacher education intervention?
5. How do students in a 4-week neuroscience-based teacher education course change their understandings of the NOS as a result of this teacher education course?
6. How do students change their perceptions of the NOS, neuroscience, and their integration as a result of this teacher education course?

Overview of the Dissertation

In this section, I briefly outline the chapters that will constitute the rest of the dissertation. Chapter II provides an outline of the research literature relevant to the research objective, including information on the NOS, neuroscience in education, science teacher education, and situated learning. Additionally, Chapter II provides the conceptual framework that guided this study. Chapter III describes, in detail, the methodology that guided the research objective and provides information on data collection and analysis procedures. Chapters IV and V present the results of this study in a manuscript format, where each chapter is written as an individual research paper with its own abstract, introduction, literature review and conceptual framework, methods, results, and discussion. A manuscript approach was used to describe the results of this work so that the research conducted for this research objective could be formatted in a manner that facilitates publication. Chapter IV terms the 4-week teacher education strategy as a professional development intervention, where the people who volunteered for this study are called participants. Chapter V looks at the 4-week teacher education strategy as a teacher education course, where the people who volunteered for this study are called students. These terms were selected based on their appropriateness for publication for different education research journals. Additionally, these terms are often interchangeable, as a professional development intervention often takes the form of a teacher education course. Chapter VI concludes this work, including broader discussion, implications for the research objective, and areas for future research.

Limitations

There are several limitations to this research objective. First, students who enrolled in this course on the NOS were not required to also be a student of the science teacher education program, but rather had an interest in or were already teaching science in K-12 science classrooms. Second, students enrolled in this course came from a variety of science content backgrounds, as specialization in a science field was not required to enroll in the course. The participants in this study did not all possess the same bachelor's degree and thus did not have the same background knowledge. Some participants had little or no previous experience in learning neuroscience and could have influenced their participation in the study. Third, time was an important factor to keep in mind during this research process. Participants in this study came from a variety of teaching backgrounds, where some participants were pre-service teachers who have yet to garner experience in the classroom, while others have been teaching in the classroom for a number of years. For pre-service teachers, this course on the NOS occurred in the fall semester of their one-year program. The course was highly theoretical, looking at aspects of the NOS as defined via the research literature, and historically has not had any connection to classroom practice. Additionally, pre-service teachers who served as participants had no experience student-teaching or observing in classrooms. It was the responsibility of both the researcher and the participants to attempt to connect classroom practice to the NOS even prior to student-teaching experiences. Fourth, participants may not have believed that neuroscience can inform instructional practice, as this is a largely disputed aspect of including neuroscience in education. Fifth, I am the sole researcher in this study the facilitator of large-group lectures and discussions, small-group discussions and interviews with participants. Relationships built with participants over the course of the intervention could have biased the data that was collected and analyzed for the research objective.

Definition of Terms

Catalytic Group

For this study, the term catalytic group is used to refer to 6 students organized in to 2 sets of triads who met outside of class time to discuss items in the research objective. The goal of this group was to establish deeper connections between the NOS and neuroscience and to share those ideas in the next large group setting, in an iterative process for the duration of the intervention. The share-out of these ideas was meant to push forward the discussions and connections that large-group participants made between the NOS and neuroscience.

Explicit-Reflective Approach

In this research objective, an explicit and reflective approach to teaching NOS was utilized to increase students' understanding of the construction of scientific knowledge. The term explicit in this approach refers to making the NOS a cognitive learning and instructional outcome for the course (Clough, 2006). The term reflective refers to helping students make connections between the activities they experience and targeted NOS aspects, raising questions and creating situation that compel students to consider the NOS issues inherent in science (Clough, 2006).

Large Group

The total group in this research objective refers to all participants in the research objective who attended the large group sessions, as attendance was a requirement for the course. These total group participants were observed during the large group sessions; however, they did not complete any of the pre- or post-intervention surveys or reflection reports.

Main Group

The members of the class who consented to completing reflection reports and surveys both before and after the intervention are considered to be large group members. These members only participated in the large group sessions; they did not engage in any discussion-based exercises with other students outside of class time.

Nature of Science

For this study, I used the definition of the nature of science termed the ‘Lederman 7’. The ‘Lederman 7’ describes the nature of science as having seven tenets: the empirical nature of science, the difference between scientific theory and law, the creative and imaginative nature of scientific knowledge, the theory-laden nature of scientific knowledge, the social and cultural embeddedness of scientific knowledge, the myth of scientific method, and the tentative nature of science (Lederman 1999, Lederman 2007).

PD Model

This research objective utilized a professional development (PD) model that is reform-oriented and aligns with the following characteristics of reform PD: coherence with their own teaching practice, opportunities for critical reflection, and time for curricular applications (Garet, Porter, Desimone, Birman, & Yoon, 2001; Penuel, Fishman, Yamaguchi, & Gallagher, 2007). The general reference of ‘PD Model’ is referring to this reform-oriented approach.

Chapter 2

LITERATURE REVIEW

As stated in the previous chapter, the research objective aimed to develop a model for teaching the nature of science (NOS) to students that is both explicit and reflective and is embedded within a specific scientific context. This approach to teaching the NOS allows for a fruitful reflection and deeper understanding of the scientific discipline. The first part of the chapter reviews the literature that discusses the current developments and issues in science education related to the research objective. The literature review includes the NOS and the many ways that it has been assessed and taught to science educators and science students in the past few decades. Next, the review presents an overview of current research in neuroscience education and the benefits and affordances of such a research agenda. The review also includes a description of the characteristics of a reform model of science teacher professional development that is inquiry-based. Last, the review includes a summary of situated learning and the different ways in which it manifests in classrooms. The second part of the chapter describes the conceptual frameworks by which the research objective was developed, and the data were analyzed. A conceptual framework of conceptual change theory was used to analyze the data in this research objective for Chapters IV and IV, respectively.

Nature of Science

Studies on the NOS are concerned with science as way of knowing, also known as the epistemology of science, or an understanding of how scientific knowledge came to be and what factors influence its merit (Abd-El-Khalick *et al*., 1998; Bell *et al.*, 2000; Lederman, 1992; Lederman, 2007). Reform efforts in science education have led to the development of various tenets that are said to be important for students to understand about the nature of scientific knowledge. Amidst the varying lists that describe the NOS is the most commonly referred to set of tenets: the ‘Lederman 7’, which define various aspects of science that are teachable to students. Those tenets include: empirical nature of science; scientific theory and law; creative and imaginative nature of scientific knowledge; theory-laden nature of scientific knowledge; social and cultural embeddedness of scientific knowledge; myth of scientific method; and tentative nature of science (Duschl & Grandy, 2013; Lederman, 1999; Lederman, 2007). NOS manifests itself in science education research via curriculum presence, students’ and teachers’ conceptions of the NOS, and methods to improve teachers’ conceptions of the NOS.

Reform efforts in science education since the launch of Sputnik in 1957 included massive changes in the way science was taught to students (Duschl, 1990; McComas, Clough, & Almazroa, 1998). The National Science Foundation (NSF) funded curriculum reform that included the NOS and inquiry-based activities, with a major shift to teaching both processes and products in science (DeBoer, 1991; McComas *et al*., 1998). In concert with these reform efforts, a new movement of the NOS arose that shifted the philosophy of science to a view of theory development characterized by the history of science (DeBoer, 1991; Kuhn, 2012; McComas *et al*., 1998; Posner, Strike, Hewson, & Gertzog, 1982). These inquiry-based activities, however, did not provide enough attention to the NOS to change students’ or teachers’ conceptions of science (Klopfer & Cooley, 1961; Moss, Abrams, & Kull, 1998; Rowe, 1974; Tamir, 1972; Trent, 1965). In the 1980’s the NSF halted funding for curriculum projects that were supplemented by teacher professional development, bringing about the ‘Standards’ movement (Duschl & Grandy, 2013). Since the 1980’s, curriculum reform efforts continue to attempt to include a more explicit version of the NOS in inquiry-based activities where the NOS takes on a model-based view of science based on cognitive and social practices (AAAS 1990, 1993; Duschl

& Grandy, 2013; NRC 1996, 2011; NGSS Lead States, 2013). Despite large curricular adaptations to include the NOS in the science classroom, teachers and students are still focused on the theories and facts of science (Grandy & Duschl, 2013; McComas *et al*., 1998).

Research from the 1950's to the 1980's was largely based on curriculum adaptations coupled with discovering what exactly characterized students' and teachers' conceptions of the NOS. Klopfer and Cooley (1961) focused on surveying students and teachers to better understand their conceptions about science using the Test on Understanding Science (TOUS). Their initial findings illustrated that both students and teachers held naïve views of the NOS. Despite any attempt at curricular reform, research and improvement needed to focus on teachers as their views were thought to translate to student thinking (Klopfer & Cooley, 1963; Duschl & Grandy, 2013; Carey & Stauss, 1968; Welch & Walberg, 1972). More recent research further illustrates this idea that in-service teachers' views of the NOS influence their instructional practice and how their students come to know science; in-service teachers' conceptions of the NOS are naïve at best and students also hold many of those misconceptions (Brickhouse, 1990; Irez, 2006; Lederman, 1992; Lederman, 1999; Lederman, 2007; McComas *et al*., 1998; Ryan & Aikenhead, 1992). For example, Irez (2006) and Ryan and Aikenhead (1992) found that in-service teachers and students both value the scientific method as the way to conduct science, respectively. Despite long-term efforts in constructivist learning pedagogy, many teachers still hold traditional beliefs about teaching, learning, and the nature of science, most likely because some aspects of the NOS are very hard for teachers to change given the deep philosophical roots of the NOS (Aguirre, Haggerty, & Linder, 1990; Mesci & Schwartz, 2016; Tsai, 2010).

Research in improving pre-service teachers' ideas about the NOS include a variety of approaches, including using case studies from the history of science and both explicit and implicit approaches to teaching the NOS. Initial curricular reform efforts attempted to use implicit approaches to teaching the NOS through students engaging in inquiry-based science activities (Jelinek, 1998; Klopfer & Cooley, 1961; Moss, Abrams, & Kull, 1998; Rowe, 1974; Tamir, 1972; Trent, 1965). Trent (1965) found that students who participated in the newly developed Physical Science Study Committee (PSSC) curriculum project did not have superior understandings of science compared to traditional students, despite engaging in inquiry-based science activities. Shifting away from the implicit approach to teaching the NOS, researchers found that PST's benefitted from explicit attention to the NOS in a variety of courses, including science method courses, science content courses, science research experiences, and student teaching (Abd-El-Khalick, 2001; Abd-El-Khalick & Lederman, 2000; Abd-El-Khalick *et al*., 1998; Akerson *et al*., 2000; Akerson *et al*., 2006; Bell *et al*., 2000; Koenig *et al*., 2012; Lederman, 1992; Schwartz *et al*., 2004; Schwartz & Crawford, 2004). For example, Lederman, & Crawford (2004) found that after engagement in a science research internship with explicit reflective attention to NOS, PST's had tremendously increased understandings of the NOS, and were better able to connect aspects of NOS to their experiences and to other aspects of the NOS.

Neuroscience in Education

The field of neuroscience has undergone rapid expansion since the U.S. government declared the 1990's as "the Decade of the Brain" (Geake, 2004; Geake & Cooper, 2003; Varma, McCandliss, & Schwartz, 2008). Given that the human brain is the organ of learning, the function of the human brain has raised interest not only in the community writ large but also in the field of education. This interest revolves around the desire to better understand the mechanisms that underline learning and the formation of memory (Ansari *et al*., 2011; Geake, 2004; Geake & Cooper, 2003; Goswami, 2006; Hardiman, Rinne, Gregory, & Yarmoliskava, 2012; Pickering & Howard-Jones, 2007; Serpati & Loughan, 2007). In fact, neuroscience has infiltrated our daily lives to such a great extent that people are likely to believe theories in journals and newspapers when they include irrelevant images of brain scans as opposed to theories that are not accompanied by these images (Ferrari, 2011; McCabe & Castel, 2008; Weisberg, Keil, Goodstein, Rawson, & Gray, 2008). There is arguably a great opposition in allowing neuroscience to inform educational theory and vice versa due to their disparate philosophies and potential reductionist effects on one another. However, greater progress has been made in bridging the two-way street between neuroscience and education, as there is a clear need to address levels of neuroscientific literacy of teachers (Bruer, 1997; Geake, 2004; Geake & Cooper, 2003; Pickering & Howard-Jones, 2007; Purdy & Morrison, 2009; Willingham, 2009). Unfortunately, some of this progress has resulted in a sub-field of products that claim they are brain-based, though they are riddled with misinformed ideas about the brain, termed 'neuromyths' (Ansari *et al*., 2011; Atherton & Diket, 2005; Goswami, 2006; Sylvan & Christodoulou, 2010; Willingham, 2006). There is a greater need not only to publish neuroscientific findings formally and informally so that educationalists have access to their information, but also specifically address educationalists' levels of neuroscientific knowledge as it relates to learning (Hardiman *et al*., 2012; Sylvan & Christodoulou, 2010; Willingham, 2009).

Few studies have specifically addressed the successes and failures of teaching neuroscience to in-service teachers, and even fewer studies have focused on the effects of teaching PST's neuroscience (Bernardon, 2013; Dubinsky, 2010; Dubinsky *et al*., 2013; Roehrig et al., 2012). Of the few studies that have been published, they all share in common the use of a summer professional development workshop created by the Society of Neuroscience. These workshop series, termed BrainU, aim to teach practicing teachers about neuroscience topics that relate to learning and education. BrainU utilizes inquiry-based learning techniques to teach a variety of neuroscicentific concepts, including brain structure and function, how synapses work, synaptic plasticity, learning and memory, and emotions and mirror neurons. In addition to the work done at BrainU to foster deeper understandings of neuroscience for teachers, researchers have also investigated the pedagogical implementation of these concepts by the teachers who participated in the BrainU workshops. For example, Roehrig *et al.* (2012) found that teachers who participated in BrainU workshops received higher scores via observation on the effect of their lessons on students' understanding of scientific processes and the nature of experimentation.

Although there are many topics that can be discussed in neuroscience that may have applications in education, there are three distinct topics that provide an elementary grounding in the discipline that may provide useful information for teachers to apply to their practice. Those three neuroscience topics include memory, attention, and emotion regulation. These three topics were selected based on an initial survey of the content areas provided in BrainU workshop materials. Then, the researcher engaged in a professional consultation with a neuroscience education expert to confirm the relation of these topics to neuroscience education and teacher practice (A. Holland, personal communication, June 9, 2017). Lastly, a survey of current and relevant neuroscience research relevant to education was conducted to confirm these three neuroscience topics. For each of these three topics, participants of this study engaged in a content review of the topic and a lesson study of a K-12 science lesson that taught the neuroscience topic to students in an inquiry-based learning format. The BrainU workshops provide inquiry-based lesson plans and activities for each of these concepts: memory, attention, and emotion regulation

(MacNabb, Brier, Teegarten, Schmitt, Drager, Thomas, & Dubinsky, 2006). A review of the research backing each of these three topics follows.

In its most primal form, the creation of memory involves the establishment of synapses that connect neurons together. Conversations about memory in education can take many forms, including learning about the idea of synapses and their connections, discussions of neuroplasticity, and learning about multi-modal memory, concepts for which recent research on the importance of neurocognitive theory in science education advocate (Anderson, 1997, 2014). The three phases of memory are differentiated into encoding, consolidation, and retrieval, for which the first and third phases (encoding and retrieval) bear significant ties to teaching, because teachers facilitate the phase of encoding, while assessments house the phase of retrieval. Retrieval is largely based on mechanisms of encoding, and its failure results when either information is not stored in memory (i.e. it was never learned) or when the retrieval processes do not allow for successful recovery of the stored information). Additionally, it is useful to understand that memories which are encoded in learning experiences can become dependent on context and/or emotional state (Bower, Monteiro, & Gilligan, 1978; Daselaar, Rice, Greenberg, Cabeza, Johnson, & Hyman, 1997; Holland & Kensinger, 2010; Nadel, Samsonovich, Ryan, & Moscovitch, 2000; Tulving & Psotka, 1971). Additionally, if students are to be tested on content that they experience in the classroom, it is important for teachers to understand how different retrieval cues can affect ones' ability to retrieve information from stored memory (Bower *et al*., 1978; Cahill & MacGaugh, 1995; Godden & Baddeley, 1975; Goodwin, Powell, Bremer, Hoine, &, Sterne, 1969; Tulving & Psotka, 1971). In discussing multi-modal memory, it is useful for teachers to understand the two models of consolidation (the second phase of memory): the standard model of consolidation and the multiple trace theory of consolidation (Gilboa, Winocur, Grady, Hevenor, & Moscovitch, 2004; Takashima *et al*., 2006). The multiple trace theory of consolidation gives support for the continued use of the medial temporal lobe in retrieving contextual and temporal details of memory, and thus the continued relevancy of context and mood on memory retrieval (Gilboa *et al*., 2004). Additionally, teachers should discuss the myth of visual-audio-kinesthetic learning styles (also termed VAK learning styles), as a fruitful application of the importance of multi-modal memory to student learning and teacher pedagogy.

In addition to learning about the various research contributing to the neuroscientific understanding of memory, teachers should also be made aware of the neuroscience contributing to the understanding of attention. Teachers should learn about how attention has a limited capacity whereby students must select what they take in from their surroundings for processing in memory. Additionally, teachers should understand the two models of attention (early selection model and late selection model) and how they contribute to the way in which students respond to stimuli under differing classroom conditions. The Posner Paradigm and how information in the environment is either degraded or attenuated provides evidence for better understanding the different models of attention (Posner, 1980; Treisman, 1969). The two attentional networks, the ventral attentional network and the dorsal attentional networks, helps to differentiate between top-down and bottom-up control, better explaining how in some cases, attention is never at limited capacity when an unexpected (and especially fearful) stimulus is presented (Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000; Hopfinger Buonocore, & Mangun, 2000; Ohman, Flykt, & Esteves, 2001). Teachers should also be given space to discuss the dual-hemispheres theory, where although there may be dominance for a specific task to either the right or left hemisphere, this does not mean that knowledge is not present in the contralateral hemisphere; rather, it more so indicates the ease and quickness with which one can complete the specific task. This discussion space has the ability to give insight into discussing right-brained versus left-brained students.

Lastly, teachers should learn about the various theories of emotion, how they influence academic performance, and the ways in which emotions can be effectively regulated. Teachers should learn about the differences between physiological theories of emotion (the James-Lange theory and the Cannon-Bard theory) and more cognitive theories of emotion (the Schachter-Singer theory, Lazarus theory, and Constructivist theory), especially because constructivist learning theories are a progressive yet widely desirable method to adopt for teaching in K-12 classrooms. Emotions can also be regulated; the most effective method of emotion regulation (to date) is cognitive reappraisal, where one changes the way they think about an emotional event so as to limit its emotional impact. Cognitive reappraisal is associated with lower activity in the amygdala, a structure in the brain that houses and processes emotion, as well as increased activity in the prefrontal cortex. This finding suggests that it takes higher-order thinking skills to be able to effectively regulate one's emotional response to a stimulus (Ochsner *et al*., 2004). Emotion regulation can have an impact on the classroom via students' lived experiences that they bring into those classrooms as well as academic performance as measured through standardized testing (Graziano, Reavis, Keane, & Calkins, 2007; Kim *et al*., 2013; Goldin, Manber-Ball, Werner, K., Heimberg, & Gross, 2009). Students who can successfully regulate their own emotions perform at a higher level than their counter parts on both math and early literacy standardized tests (Graziano *et al*., 2007).

Science Teacher Education

The spawn of the standards movement that describes higher and more rigorous student standards put pressure on developing professional development (PD) for teachers to supplement the reform standards put in place. Yet teacher development within this reform movement is fragmented, and there is no clear consensus on the best strategies to improve PD (Fishman, Marx, Best, & Tal, 2003). Possibilities for teacher PD include both formal and informal opportunities such as action research projects, school-based PD, workshops and conferences held by established organizations, graduate level programs, their interactions with other teachers, and their roles as parents (NRC, 2000b; Wilson & Berne, 1999). Yet despite the potential usefulness of these resources to help teachers develop inquiry-oriented teaching practices, teachers still view themselves as deliverers of scientific facts, and many teachers are reluctant to engage in PD due to its traditional and ineffective reputation (Aguirre *et al*., 1990; Tsai, 2010; Wilson & Berne, 1999; Darling Hammond & McLaughlin, 1995). Researchers of teacher development focus on the effectiveness of the reform model for developing teachers, types of knowledge that teachers should possess to be good teachers, and the effectiveness of teacher development programs.

Reform efforts for in-service teacher PD consider the benefits of transitioning to a 'reform model' because a traditional model is one that many teachers find ineffective and/or irrelevant to their personal classroom practice (Penuel *et al*., 2007). To have effective in-service PD, teachers must value the coherence of the program with that of their own teaching practice, have the opportunity for critical reflection, and be given time to implement curricular strategies (Darling-Hammond & McLaughlin, 1995; Fishman *et al*., 2003; Garet *et al*., 2001; Kubitskey & Fishman, 2006; Penuel *et al*., 2007; Putnam & Borko, 2000). Garet *et al.* (2001) found that the sustained, intensive, and coherent nature of the Eisenhower Professional Development Program that focused on their content area correlated with higher reports of teacher self-reported changes in practice. Research has also investigated the nature and use of curriculum materials in teacher

PD, and what materials are considered effective for teachers (Ball & Cohen, 1996; Davis & Krajcik, 2005; Kubitskey & Fishman, 2006). Research has also focused on establishing communities of practice, which allow for teacher to be openly and efficiently collaborative and critical of one another, providing feedback and working together within the context of the shared community to gain both professional and conceptual knowledge (Akerson, Cullen, & Hanson, 2009; Darling-Hammond & McLaughlin, 1995; Garet *et al*., 2001; Grossman, Wineburg, & Woolworth, 2001; Palinscar, Magnusson, Marano, & Brown, 1998; Wenger, 1998; Wenger, 2000; Wilson & Berne, 1999).

Many research avenues for pre-service teacher preparation programs focus on the coherence of the content that students are required to learn, including content courses, methods courses, and courses on the philosophy, history, or sociology of education (Abd-El-Khalick 2001; Abd-El-Khalick & Lederman, 2000; Koenig *et al*., 2012; Magnusson *et al*., 1999; NRC, 2000b). In addition, research focuses on the effectiveness of student teaching experiences as a component of teacher preparation (Abd-El-Khalick, 1998; Akerson *et al*., 2006; Bell *et al*., 2000; NRC, 2000b). For example, Bell *et al*. (2000) found that student teachers exhibited low levels of transfer of the NOS to classroom practice, illustrating the gap that exists between theoretical knowledge and classroom practice. Other avenues of research include identity development and self-efficacy, PST's conceptions of science teaching, learning, and the nature of science, and development of inquiry-based teaching methods (Aguirre *et al*., 1990; Cakiroglu, Cakiroglu, & Boone, 2005; Cantrell, Young, & Moore, 2003; Crawford, 2007; Darling-Hammond, 2000; Irez, 2006; Lederman, 1999; Luehmann, 2007; Mensah, 2009; Tsai, 2010). For example, Mensah (2009) illustrated the success of opportunities for collaboration between PST's in the form of a book club that addressed issues of diversity and culture in the classroom, altering teachers' conceptions about the role of science teaching and learning. Despite this forward progress, PST's often complain that what they learn is too disjointed from their student teaching experiences, and these experiences are more likely to influence their future practice, inhibiting transfer of knowledge from their coursework to the classroom (Akerson *et al*., 2006; Brickhouse, 1990; NRC, 2000b; Luehmann, 2007). Although it is critical to establish more tightly integrated teacher education programs given these findings, teachers who have gone through these programs are still more likely to be successful in teaching (Darling-Hammond, 2000).

In addition to revamping the ways in which teachers engage in PD, researchers also consider what knowledge teachers should be developing to become or remain effective teachers. While initial conceptions of the knowledge teachers needed was limited to pedagogical knowledge and content knowledge, recent developments have expanded this idea to include hybrid forms of knowledge, such as pedagogical content knowledge and pedagogical context knowledge, which incorporate both content and pedagogy in addition to other factors that affect science teaching (Abd-El-Khalick & BouJaoude, 1997; Barnett & Hodson, 2001; Magnusson *et al*., 1999; Putnam & Borko, 2000; NRC, 2000a; Shulman, 1986; Wilson & Berne, 1999). The development of pedagogical content knowledge and pedagogical context knowledge emphasizes the uniqueness in teaching science in that a general set of pedagogical tools coupled with content knowledge is not sufficient to be an effective teacher.

Situated Learning

The philosophical viewpoint of social constructivism altered the ways in which educationalists think about how the learner is connected to the learning space and to the other people within that space. Spearheaded by Leo Vygotsky, social constructivism focuses on the individual's learning as it results from interactions within the group, and the learning that results from these social interactions is critical for participation in the lived-in world (Lave & Wenger, 1991). Situated learning, then, focuses on the development of skills and conceptual knowledge as it is embedded within the context of learning; that context informs the ways in which those learners will develop their ideas about the knowledge domain in which they work (Brown, Collins, & Duguid, 1989). The acquisition of this knowledge gives learners the opportunity to participate in the community of practice at a higher level; learners move from a more peripheral location within the community of practice to a more centralized one as they develop knowledge about the subject at hand. Thus, the process by which learners engage in a community of practice based on their developing knowledge is termed legitimate peripheral participation (LPP) (Lave & Wenger, 1991). Situated learning has been investigated in many forms since its introduction in 1989, including instructional design, discourse, communities of practice, and issues of identity and language.

Variations in instructional design have incorporated ideas of social constructivism and situated learning, including project-based learning, anchored instruction, and cognitive apprenticeship (Krajcik & Blumenfeld, 2006; Cognition and Technology Group at Vanderbilt, 1992; Collins, Brown, & Holum, 1991). Project-based learning allows for students to solve problems anchored about observations that they have made about the world as they are situated within the practices of science (Krajcik & Blumenfeld, 2006). As a result, students are more interested and motivated in learning science and perform better both on low-stakes and high-stakes exams (Blumenfeld, Soloway, Marx, Krajcik, Guzdial, & Palincsar, 1991; Boaler, 1997; Geier *et al.*, 2008; Kanter, 2010; Krajcik, Blumenfeld, Marx, Bass, Fredricks, & Soloway, 1998; Shepherd, 1998). In addition, students who traditionally struggled in science classrooms preform at a higher level when they engage in project-based learning (Boaler, 1997; Meyer, Turner, & Spencer, 1997).

Anchored instruction is an alternative approach to engaging learners in science through some sort of technology-based anchor (Cognition and Technology Group at Vanderbilt, 1992). Multiple studies have resulted in a positive impact on involvement in instruction and attendance (Williams Glaser, Reith, Kinzer, Prestige, & Peter., 1999) and problem-solving skills and motivation (Bottge, 1999; Bottge, Heinrichs, Chan, & Serlin, 2001; Etheris & Tan, 2004; Serafino & Cicchelli, 2003; Shyu, 2000). For example, Bottge *et al.* (2001) found that remedial mathematics students that utilized enhanced anchors in the form of video-discs performed at the same level as traditional students on the post-test, despite major differences in pre-test scores.

Cognitive apprenticeship is yet another alternative instructional paradigm for teaching students the reasoning and strategies that experts employ when they work to solve complex or real-life tasks (Collins *et al*., 1991). Cognitive apprenticeship as an instructional approach has value in increasing learners' knowledge through modeling, scaffolding, and reflection (Cash, Behrmann, Stadt, & Daniels, 1997; Charney, Hmelo-Silver, Sofer, Neigeborn, Coletta, & Nemeroff, 2007; Duncan, 1996; Fishbach, 1993; Hendricks, 2001; Schraw, Crippen, & Hartley, 2006). For example, Hendricks (2001) compared traditional instruction to a form of cognitive apprenticeship instruction where students engaged in conversations about cause and effect within the context of scientific research. The instructor used modeling as a method for helping students understanding. The results of the study indicated that students that engaged in situated instruction possessed higher levels of understanding of cause and effect.

Situated learning is also investigated via the context in which learning occurs: communities of practice. Lave and Wenger define communities of practice as formed by people who engage in collective learning about a specific human endeavor (Lave & Wenger, 1991; Wenger, 2000). Communities of practice vary based on the individuals that which comprise various communities, and within those communities, learners can develop identities appropriate to that community (Handley, Sturdy, Fincham, & Clark, 2006; Lemke, 1997, 2002). Communities of practice have been studied through identity, language and discourse, and participation in the community itself. Identity construction can occur through language as representation in communal discourse participation (Brown, 2004; Brown, Reveles, & Kelly, 2005; Wortham, 2003, 2004). Participation is central to situated learning; as students participate in the community, they construct their own identities as well as co-construct the identity of the community through their interactions with others (Handley *et al*., 2006; Lemke, 1997; Lemke, 2002; Wenger, 2000). Participation also allows for the development of one's practice, the tools and language necessary to act within the community (Handley *et al.*, 2006; Lemke, 1997, 2002). Because participation is dependent on action in addition to the connections that are made within the community, researchers investigate the factors that enable and inhibit participation and identity construction in communities of practice (Brown, 2004; Lemke, 1997, 2002; Wenger, 1998, 2000; Wortham, 2003, 2004).

Conceptual Framework

A social constructivist learning theory was employed in guiding the activities for the large group lesson setting specific to this research objective. Social constructivism guided the teaching of the NOS to students both historically at the university and for the semester in which the research objective took place. Social constructivism claims that knowledge is fundamentally social in nature, that knowledge neither can be separated from the learning context nor that the learning context is separate from social and cultural influences (Driver, Asoko, Leach, Mortimer,

& Scott, 1994; Palinscar, 1998). Therefore, learning is an active process by which knowledge is constructed amongst group of people and is culturally and contextually specific to the community of learners who develop said knowledge (Palinscar, 1998). Additionally, the learning context is constantly changing because the learners, in addition to the socially and culturally shaped contexts, are also changing (Palinscar, 1998). The NOS course used for this research objective employed a social constructivist pedagogy because it adheres to a definition of scientific knowledge that it also socially constructed through an accepted and shared practice, whereby the language or culture of science is used to interpret nature (Driver *et al.*, 1994). The course focused on a collaborative nature of learning where students engaged in discussions and co-teaching models to construct a socioculturally specific definition of the NOS over the course of the semester. This definition of the NOS was specific to the community of learners, in this case the participants, and their past, personal experiences that they brought with them to the classroom. Through the NOS course, learners were more deeply integrated into the knowledge community of both science and science education.

The conceptual framework utilized in this study was the conceptual change theory. Conceptual change theory contributed to analyzing the data in Chapter IV and Chapter V by providing a framework for which participants' understandings of the NOS progressed and changed over the duration of this intervention. A brief review of each of the conceptual framework follows.

Conceptual Change

The conceptual change model (CCM) is a model that is based on a theory of conceptual change, which posits a process by which people's central, organizing concepts can change from one category to another, which is incompatible with the first (Abd-El-Khalick & Akerson, 2004;

Clough, 2006; Hewson & Hewson, 1984; Posner *et al*., 1982). There are at least three types of categories to represent entities, or things in the world: matter (things), processes, and mental states (Chi, Slotta, & de Leeuw, 1994). The entities that reside within those three different categories differ ontologically from one another and bear no overlap; if those entities bear any overlap at all, they should be considered to reside within only one category. Chi *et al.* (1994) notes that many mis- or alternate conceptions, especially those about scientific concepts, are due to wrongful categorization of the scientific entity as matter (thing) rather than a process. For example, Chi *et al.* (1994) describes how many naïve views of electric currents would categorize it as a thing, whereas physics experts categorize electric currents as a process, whereby the induction of an electrically charged particle into an electric field allows for the electric current to exist.

To effectively change one's conception of an entity from the current category in which it resides to a new category, the new category must have: higher status in terms of intelligibility, plausibility, and fruitfulness (Abd-El-Khalick & Akerson, 2004; Hewson & Hewson, 1984). However, the ability of a student to change their categorization of an entity is dependent on something called their conceptual ecology, or their epistemological commitments, metaphysical beliefs, and other knowledge they may possess about the concept itself (Abd-El-Khalick & Akerson, 2004; Hewson & Hewson, 1984; Posner *et al.*, 1982). In this sense, the CCM viewed conceptual change as purely cognitive, similar to the ways in which Kuhn described the cognitive aspects of paradigm shifts. As a result, the CCM does not deny the presence of other factors that influence conceptual change, rather it simply does not consider the role of affective variables that mediate learning spaces (Abd-El-Khaik & Akerson, 2004). It has been more recently argued that many factors can influence the conceptual change process, including the affective, motivational, and contextual (Abd-El-Khalick & Akerson, 2004; Pintrich, Marx, & Boyle, 1993). As a result, understanding the CCM through a 'learning ecology' may be better suited for educational settings. A learning ecology as the grounding context for CCM encompasses cognitive, motivational, affective, contextual, social, and cultural factors in describing conceptual change (Abd-El-Khalick & Akerson, 2004; Pintrich *et al.*, 1993).

The CCM has been used to investigate the role of conceptual change on changing students' and teachers' deeply rooted ideas about the nature of scientific knowledge (Cho, Lankford, & Wescott, 2011; Clough, 2006; Mesci & Schwartz, 2016). If the theory of conceptual ecology is used to understand how the CCM explains students' understanding and re-categorization of the NOS, it assumes that scientific conceptions are superior to other conceptions for making sense of the world (Abd-El-Khalick & Akerson, 2004). In other words, students are expected to construct scientific concepts meaningfully even when those concepts and the nature of scientific knowledge conflict with their cultural and personal norms, values, and beliefs related to their life-world (Aikenhead & Jegede, 1999; Pintrich *et al*., 1993). The problem of alienation of indigenous cultures from science classrooms bears large importance in science teaching and learning and will be considered when investigating the ways in which students change their conceptions of the NOS in the context of this study.

Investigations of methods of instructions for teaching the NOS through a CCM have also been studied (Cho *et al.*, 2011; Clough, 2006). The explicit, reflective approach to teaching the NOS is rooted in guidelines for teaching NOS that align with CCM. Those guidelines include: making the NOS an explicit instructional outcome, having metacognitive discourse about shifts in understanding of the NOS, discussing the status of ideas in terms of the criteria for shifts to a new category (plausibility, fruitfulness, and intelligibility), and the justification for shifting ideas based on their status should be made explicit in discourse (Abd-El-Khalick & Akerson, 2004; Clough, 2006). In addition to creating an explicit and reflective method for teaching NOS, a highly contextualized approach to teaching the NOS is helpful for students to better understand the highly theoretical aspects of NOS. NOS instruction can be contextualized by utilizing students' mis- or alternate conceptions about the NOS in addition to using a scientific content area to better understand the complicated nature of scientific knowledge (Clough, 2006). Students' understandings of the NOS depend on the scientific content that frames the NOS discussion, so it is important to select a topic that is both largely present in the media and familiar to students, to a certain extent (Abd-El-Khalick & Akerson, 2004; Clough, 2006). Additionally, the CCM has roots in Vygotskian social constructivism, whereby knowledge is not personally constructed but socially mediated (Abd-El-Khalick & Akerson, 2004; Pintrich *et al.*, 1993). Because the learning space and the knowledge that is produced in that space is socially constructed, teaching the NOS through an explicit, reflective, and contextualized approach must also utilize embarking on students' legitimate peripheral participation to initiate and push forward conceptual change. This study will consider the CCM model and its complicated nuances in addition to looking at the ways in which students interact in a learning space through legitimate peripheral participation.

Summary

The literature summarized in this chapter provides a context by which the methodology, described in the next chapter, can be understood and evaluated. The review of the NOS and neuroscience in education gives insight into the content that which guides the research objective, and the information that which the participants learned during the study. The methodology demonstrates the ways in which situated learning and the reform model of professional development were used to answer the six questions that guide the research objective. Additionally, this review frames the lens through which the researcher analyzed the data which was purposefully collected to answer the six questions.

Chapter 3

METHODS

As summarized in the foregoing Literature Review, the principles of situated learning are helpful for improving learning across all levels of education, and across the lifespan, including teacher professional education. By situating teacher professional education in a context of theory and practices that is pertinent to daily practice, learning is enhanced and more readily transferred into the classroom. In this study, situated learning provided a guiding framework for the design and implementation of the research. A guiding framework indicates how situated learning provided a basis for the creation of a structure for professional development that was grounded in the daily classroom experiences of teachers. An alternate approach to NOS instruction was developed and utilized in this study, where large group class meetings were interspersed with small, catalytic group discussion sessions. In the large group settings, the NOS was embedded in curriculum-relevant examples (i.e. recent innovative neuroscience curricula suitable for school level), whereby students analyzed the potential connections of neuroscience to the NOS and daily classroom practice. Moreover, the design of the professional development learning experiences emphasized student-centered discussion groups that promoted a sense of communities of practice. Small, catalytic group discussions were intermixed with the larger group setting to enhance the diversity and creativity of ideas generated in these discussions. A framework of conceptual change also provided a rationale for which the researcher could better understand the ways in which participants' understandings of the NOS and neuroscience progressed over the duration of this intervention, as presented in Chapter IV. Additionally, the situated structure of the large and small group lesson settings frames the utilization of legitimate peripheral participation (LPP) as a rationale for analyzing the data presented in Chapter V.

The Research Questions

This chapter outlines the six research questions. The research questions were answered through two individual research papers that were prepared for publication. The research questions for this study were as follows:

1. What are the dynamics that characterize the interactions within a science teacher education intervention (a large group setting), when students discuss the integration of neuroscience with the NOS, and how do those dynamics change during a sequence of opportunities to reflect and engage in discussions about the integration of the NOS with neuroscience?
2. To what extent do pre-service and in-service teachers change their understandings of the NOS during a sequence of opportunities to reflect and engage in discussions about the integration of the NOS with neuroscience?
3. How do participants' attitudes and beliefs on the integration of neuroscience and the NOS change as they engage in the four-week teacher education intervention on neuroscience and the NOS?
4. Overall, how effective was the catalytic group function in the integration of neuroscience and the NOS during the 4-week teacher education intervention?
5. How do students in a 4-week neuroscience-based teacher education course change their understandings of the NOS as a result of this teacher education course?
6. How do students change their perceptions of the NOS, neuroscience, and their integration as a result of this teacher education course?

Questions one, two, three, and four were answered in the first embedded research paper (Chapter IV), and questions five and six were answered in the second embedded research paper (Chapter V).

Research Design

Multimethod or multivariate studies emerged in the 1950's with the emergence of multiple forms of social science research (Creswell, 1999). These types of studies were later termed 'mixed-methods', as the simple term 'mixed' allowed for a larger blanket to cover the ways in which qualitative and quantitative data could inform one another (Creswell, 1999). There are two main ways in which mixed-methods research is conducted. The first model of mixed-methods research is a sequential model, where either one form of data collection stems from the results of another type of data collection. For example, a qualitative-quantitative model considers a robust set of qualitative data with the later incorporation of quantitative measures to attempt to generalize qualitative findings (Creswell, 1999). Alternatively, a quantitative-qualitative model surveys many participants using quantitative measures and attempts to then look at a more in-depth picture to establish and reinforce quantitative findings (Creswell, 1999). The second type of mixed-methods research converges both qualitative and quantitative data, a model in which both forms of data inform one another and from which the findings arise. The validity of mixed-methods research stems from the triangulation of data, with the assumption that more or better information can be gained from having multiple qualitative and quantitative data sets rather than from one method alone (Creswell, 1999).

The qualitative method portion of mixed-methods research gives the opportunity for a rich and substantial analysis of non-quantitative evidence of actions, events and dynamics of human interaction within a specified context of a research study. Methods include direct observation, observation using coding instruments, interviews, questionnaires with open-ended responses, and other means of documenting evidence pertinent to the study objectives (Creswell, 2012). In the present study, a convergence model of mixed-methods research was utilized to carry out the research objective. The qualitative data were organized into a collective case study format, whereby three cases were purposefully selected to further describe the multiple perspectives of participants in the intervention (Creswell, 2012). Both qualitative and quantitative data were collected simultaneously and informed one another during the data analysis process. Qualitative data included open-ended surveys, observations, and written reports. Quantitative data included non-parametric Likert-scale surveys.

Field Setting and Participants

This study took place at a large university in the northeast United States. This study was approved by the University's Institutional Review Board [*Appendix A*]. The investigation recruited 17 students enrolled in a class that teaches the nature and practices of science. These 17 students form the 'large group' of participants in the research objective. The group of participants had a variety of prior teaching experience and came from a variety of science and non-science backgrounds. Pre-service and in-service teacher education students were chosen for this investigation because there is insufficient evidence from the literature of an effective strategy to help prospective and current teachers use the NOS in their classrooms (Abd-El-Khalick & Lederman, 2000; Abd-El-Khalick *et al.*, 1998; Akerson *et al*., 2006; Bell *et al*., 2000; Irez, 2006; Koenig *et al*., 2012; Lederman, 1992, 2007; Ryan & Ikenhead, 1992; Schwartz *et al*., 2004). Of those 17 students, 11 students opted to fully participate in the research study, where they completed surveys and reflections outside of class time and those items were collected and analyzed by the researcher. These 11 students form the 'main' group participants in this study.

Of those 11 students, six were females. Seven participants identified at Caucasian/white, two identified as African/African-American/black, and two identified as Asian/Asian-American/Pacific Islander. Remunerations for participation in the study consisted of a $30 electronic gift card.

The five 'large group' participants who were not considered part of the 'main' group were enrolled in the course and participated in the in-class activities that established the large-group portion of the intervention. Data collected for these five participants only include lesson plan analyses and observations (to be described in more detail later in this chapter). 6 of the 11 main participants in this study also acted as 'catalytic group' participants. They met in triads outside of class to further discuss the connections between neuroscience and the NOS. Triad 1 consisted of two Caucasian/White females and one African/African-American/Black male. One of the females and one male were enrolled in the science education program at the university, and the third female was enrolled in the deaf-education program but was also seeking secondary science education certification. The two females in this triad held a bachelor's degree in neuroscience. The male participant held an advanced master's degree in biology. All three participants noted that they enrolled in the course to learn more about the nature of science and because they wanted to learn directly from the professor of the course. Triad 2 consisted of one Caucasian/White male, one Asian/Asian-American/Pacific Islander female, and one African/African-American/Black female, all enrolled in the science education program at the university. All three of the participants in Triad 2 held a bachelor's degree in a science field and enrolled in the course because they were instructed to by their advisors as a requirement to complete their degrees.

Participants for this study were enrolled in a course on the nature and practices of science. This course satisfied the science disciplinary requirement that pre-service and in-service education students must fulfill to complete their certification programs and graduate from the college. Additionally, other participants enrolled in this course that were not students of the science education program were either already teaching science in K-12 science classrooms or had the desire to teach science in the future. This course on the nature and practices of science was only offered in the fall semester each year. The researcher solicited participants enrolled in this course by presenting the research study and IRB consent forms on the first day in which the course commenced [*Appendix B, C*].

The Research Procedures

This study utilized a four-week professional development intervention for pre-service and in-service teachers that was folded into the middle of the NOS course in which participants were enrolled. In the first few weeks of the course, classroom discussions focused on the NOS were largely theoretical in nature. Participants were assigned various readings from the literature on the NOS and came to these discussions prepared to discuss those readings [*Appendix D*]. When the four-week intervention commenced, participants continued to read assigned readings in preparation for discussions related to the research. All students enrolled in the class who qualified to participate in the study were asked to engage in the large group discussions. A subset of six participants met in two triads and discussed the NOS and neuroscience in catalytic groups in addition to their discussions in class.

Large Group Lesson Setting. All 17 participants in this investigation engaged in large-group discussions over the course of the semester during the assigned class time. During the classroom discussions on neuroscience, participants first engaged in a mini-lecture about three neuroscience topics that specifically related to inquiry learning: memory, attention, and emotion regulation [*Appendix E, F, G*]. These topics were chosen through a series of research steps carried out by the researcher. First, the researcher completed a content analysis of the materials used in the BrainU workshops (Roehrig *et al*., 2012). Next, the researcher engaged in a consultation with a neuroscience education expert, who confirmed the categories that were most explicitly relatable to educational practice (A. Holland, personal communication, June 9, 2017). This consultation provided the three content areas used in this study: memory, attention, and emotion regulation. Last, the researcher surveyed the relevant neuroscience literature for each of these three themes and used this information in the mini-lectures that took place in the large group sessions.

After the mini-lecture, participants completed a lesson study, where they looked at and annotated lessons that had been previously written that illustrated a K-12 school-level curriculum example of how to teach that neuroscience topic to grade-school students [*Appendix H, I, J*]. These lessons were taken from the BrainU workshops, which provide inquiry-based activities for each of these concepts (MacNabb *et al.,* 2006). These lessons were chosen because of their utility in implicitly developing teachers' conceptions of the NOS in addition to the positive affect that neuroscience had on teachers' pedagogy (Roehrig *et al*., 2012). Then, students transitioned to discussing the NOS readings that were assigned for the week. These readings were selected to correlate with the neuroscience topic that was presented to them in the same session, as the goal of the study was to see how participants could make the connection between the NOS and neuroscience over the duration of the intervention. In the fourth and final large group session, participants summarized the neuroscience content that they had learned over the course of the intervention, their connections to the NOS, and engaged in a lesson planning activity related to the Next Generation Science Standards [*Appendix K*].

Although this was a four-week intervention, this research objective spanned a five-week time-period. In the first two weeks, participants engaged in two neuroscience discussions: (1) memory and (2) attention. Then, there was a one-week break from the intervention, where participants responded to an open-ended reflection with prompts [*Appendix L*]. In the last two weeks of the four-week intervention, participants engaged in two discussions: (3) emotion regulation and (4) an application session. In this application session, participants applied the neuroscience and the NOS they learned in the intervention to curriculum design. Further explanation of how the intervention progressed can be seen in Figure 1.

Catalytic Group Lesson Setting. In addition to large, whole-group discussions, a subset of six participants met as triads in two catalytic groups. These catalytic groups met outside of class time. Figure 1 illustrates how their meetings alternated with regular large group class sessions. These catalytic groups were designed to facilitate discussions about how new knowledge about the NOS gained in prior sessions of the course can be integrated with neuroscience in education as curriculum topics. In these catalytic groups, participants were asked to think about what connections can be made between neuroscience and the NOS. These sessions were facilitated by the researcher [*Appendix M*]. At the end of each catalytic group session, the catalytic group participants compiled a list of main points they discussed and formed a set of discussion questions. These questions were brought back to share with the large group to promote broader discussion. Catalytic group participants shared their discussion questions during the second and third large group sessions. This occurred in an iterative process over the course of the four-week intervention (Figure 1). Participants of the catalytic group discussions met outside of class time for one hour to have these discussions.

This intervention represents a novel aspect of the study as a strategy to enhance situated-based teacher professional development integrating the NOS and curriculum-based classroom practices within an alternating pattern of large and catalytic groups, each group with a role and discussion theme.

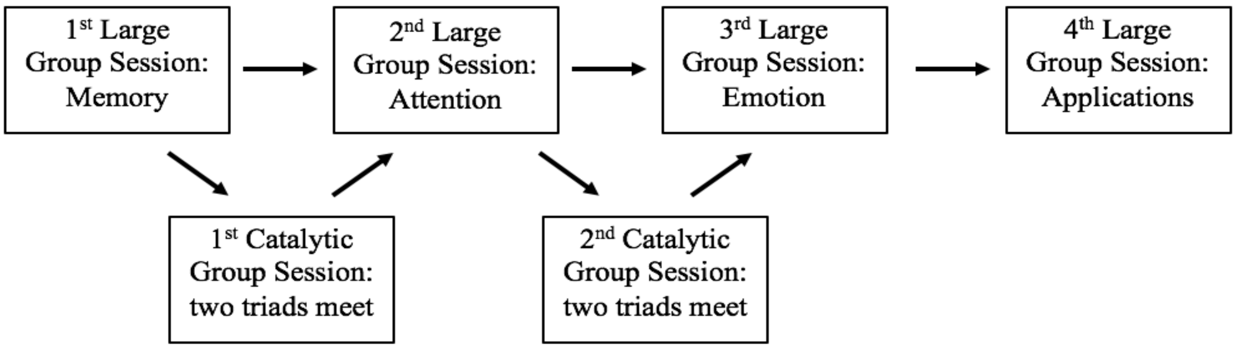

Figure 1: Design of the PD Intervention. Design of the alternating large and catalytic group discussion sessions in relation to the total class sessions showing the foci of the large and catalytic group discussions and the integration of the catalytic group discussion themes into the total group in an alternating lesson setting during a total of four class sessions following the initial introductory set of sessions on the NOS.

The timeline for the course was as follows:

Table 1

The Timeline of the Intervention as it is Embedded Within the Normal 16-week Course

Week	In-Class Participation	Out-of-Class Participation
Weeks 1 – 5	NOS Classroom Instruction	
Week 6	1st Large Group session: Neuroscience of Memory	Outside of class: 1st Catalytic Group Session: Reflection on NOS/Neuroscience

(continued)

Table 1

The Timeline of the Intervention as it is Embedded Within the Normal 16-week Course

Week	In-Class Participation	Out-of-Class Participation
Week 7	2nd Large Group Session: Neuroscience of Attention	Outside of class: 2nd Catalytic Group Session: Reflection on NOS/Neuroscience
Week 9	3rd Large Group Session: Neuroscience of Emotion Regulation	
Week 10	Synthesis of topics from Large Group Sessions 1-3 Curriculum Applications to include NOS and neuro-educational themes	
Weeks 11-16	Continued NOS Instruction	

Instruments

There were five sources of evidence collected in this investigation: surveys, reflection reports, observations, a researcher journal, and transcriptions of the catalytic group lesson setting. These sources of evidence allowed for an in-depth and robust analysis of themes for the case at hand (Creswell, 2012). The use of multiple sources sufficiently met the requirement of triangulation as a source of research validation (Creswell, 2012).

Surveys. The Students Understanding of Science and Scientific Inquiry Survey (SUSSI) [*Appendix N*] was used to identify the views of the NOS that teachers held, both before and after the intervention strategy occurred. The SUSSI is a Likert-scale survey that measures college students' views of the NOS based on six parameters: observations and inferences, change of scientific theories, scientific laws versus theories, sociocultural influence on science, imagination and creativity in scientific investigations, and methodology of scientific investigations (Liang *et al*., 2006). The parameters that are measured by the SUSSI regarding the NOS were explicitly addressed in the strategy to develop participants' conceptions of the NOS during the instructional intervention. Additionally, the SUSSI has an open-ended response section after each of the six parameters in which respondents can explain their answers to the Likert-scale items. The SUSSI was completed by participants prior to and directly after the study intervention took place.

A second survey, the Attitudes and Beliefs about NOS-Neuroscience Connections (AB NOS) Survey, was given to participants once before the intervention and once after the intervention concluded [*Appendix O*]. This survey is a Likert-scale survey that was designed by the researcher to measure participants' attitudes and beliefs about the productivity of using neuroscience to better understand the NOS and to measure how important participants believe learning the NOS is for being an effective educator. A Likert-scale matrix was used to bind Likert items according to the dimension that those questions assess. Questions in this survey either took a position/stance dimension or a sentiment/attitude dimension, and topics either informed the NOS independently or the NOS-neuroscience connections. The first 12 questions of the pre- and post-surveys are the same, per a traditional pre-post survey format, but the post-survey includes six additional questions that are more directly related to their how experiences in the intervention may have changed their attitudes and beliefs about the connections between the NOS and neuroscience.

A third, and final, survey was given to participants entitled the Demographic Survey [*Appendix P*]. This survey served the simple purpose of collecting demographic data for the participants in the study.

Reflection Reports. There were two types of reflection reports utilize in this study. First, large-group participants completed a Mid-Intervention reflection report [*Appendix L*]. This report was intended to summarize and allow participants to reflect on what they had experienced in the first two weeks of the intervention. The second type of reflection report was obtained from the triads of participants in the catalytic groups to document their perceptions of their discussions in the group [*Appendix R*]. These reports were used to summarize their experiences in the catalytic groups that were reported back to the group in the third and fourth large group class meeting. The goal was to see if the strategy enabled the catalytic group participants to spontaneously start connecting neuroscience with the NOS and be prepared to share those thoughts to the larger group with the goal of inspiring a fuller discussion of the interrelationships between the NOS and neuroscience curriculum topics. Reports were coded to identify themes of the case and correlated with responses on the survey. Participants wrote reflection reports after they engaged in the two catalytic-group discussions. Only the participants from the catalytic-group discussions wrote reflection reports and were encouraged to bring the ideas from these reports to the large-group lesson setting. The researcher had full access to the reflection reports because they were prepared digitally and sent to the researcher. As needed, e.g. for clarifications, the researcher briefly interviewed the small group participants to follow up on their writings in the reflection reports to validate and inform their thoughts that they wrote in their reports. As noted below, observations in the large group class setting focused on the way the catalytic groups interacted with each other and the larger group of participating students to document to what extent the intended communications by the catalytic groups were actually realized in the larger class setting.

Observations. The researcher was substantially involved in the intervention as instructor and participant observer. An observation protocol was used to record the dynamics of the large group interactions during the formal lessons on the NOS and neuroscience designed for this research study [*Appendix Q*]. The observation protocol included four categories that were recorded at five-minutes intervals: i.e., 1) the NOS/neuroscience content of verbal interactions, 2) cognitive characteristics of the interactions, 3) patterns of group interactions (i.e., who communicated with whom between and among the small group members and larger group of students), and 4) the ambiance of the learning environment (socio-emotional quality of the classroom environment). Each of the four, five-minute coded observations included additional written comments to clarify what was observed and provide a time-marker. A multiple coding strategy was used to complete these observations to allow for any shifts in group dynamics to be recorded in the observation protocol. To better support detection of cognitive aspects of the observation protocol, namely the verbal interactions and cognitive characteristics of those interactions, a matrix of content statements was developed for the first three large group sessions that consisted of content statements for the NOS, neuroscience, and potential connections to be made between the two subjects [*Appendix S*]. Two research assistants were recruited to fill out the observation protocol during the large group sessions. To recruit these research assistants, a digital announcement was made on the homepage for the college and assistants were selected based on their keen attention to detail and previous research experience [*Appendix T*]. The research assistants went through a training with the researcher to ensure credibility and accuracy in observations [*Appendix U*]. The research assistants were remunerated in the amount of $15/hour for the hours in which observations took place. Two research assistants were recruited to increase the validity of the observation protocol.

Researcher journal. A journal was kept by the researcher that was used to capture the dynamics of the participants' interactions during the large group lesson settings. Notes related to those interactions included how participants engaged with the activities and took note of how they attempted to integrate neuroscience and the NOS. Additionally, these notes described how catalytic group participants interacted with large group participants in the large group lesson setting, indicating how these catalytic group participants shared their ideas from their own small group discussions to stimulate further discussions in the large group setting. This researcher journal was cross-referenced with other sources of evidence in the analysis of the results for Chapter IV.

Transcriptions of catalytic group lesson setting. Audio recordings were captured for each meeting among the two triads of catalytic group members. These audio recordings documented the dynamics of conversations that occurred among these triads. The audio recordings were transcribed by the researcher, using pseudonyms to represent the participants in each triad.

Evidence Collection Methods and Analysis

The Methods for data analysis are described for the two embedded research papers that are presented in Chapter IV and Chapter V.

Chapter IV. There were six sources of evidence used in this study: the observation protocol, the mid- and post-intervention reflection reports, the SUSSI survey, the AB NOS survey, and a researcher journal. Open coding, using NVivo Software, was used to establish emerging themes in the qualitative evidence collected in the reflection reports and the SUSSI survey. The results from the AB NOS survey and the Likert-scaled items from the SUSSI survey were analyzed by examining changes in the percentages recorded for the Likert scale categories from pre- to post-administration. Based on evidence collected from the reflection reports and the survey responses, the data were triangulated to establish general themes across the multiple sources of evidence (Boeije, 2009).

Chapter V. There were four sources of evidence used to answer the questions for Chapter V: the AB NOS survey, mid-intervention reflection reports, catalytic group reflection reports, and transcriptions of the catalytic group lesson setting. Open coding, using NVivo Software, was used to analyze the participants' narrative in the written reflection reports. The quantitative items were used in a content-analysis format and analyzed alongside the written reports for each of the sub-sections of the SUSSI survey. Content analysis was then used in further integrative analyses to identify larger patterns across the different sources of the qualitative evidence for each case represented in the case-study.

Terminology variations for the manuscript papers. The results chapters (Chapter IV and Chapter V) vary in terms of the language used to describe the 4-week intervention presented in this dissertation. Chapter IV calls the intervention a "professional development intervention" where the people who volunteered for the study are called "participants". Chapter V calls the intervention a "teacher education course" where the people who volunteered for this study are called "students". These terms were selected based on their appropriateness for publication in different educational research journals. Additionally, these terms are often interchangeable with one another in teacher education. This interchangeability can be explained by considering how teacher professional development interventions often take the form of teacher education courses.

Table 2

Summary Table of Research Questions, Sources of Evidence and Analyses

Research question	Source of evidence	Analysis
1. What are the dynamics that characterize the interactions within a science teacher education class in large group settings when they discuss the integration of neuroscience with NOS, and how do those dynamics change during a sequence of opportunities to reflect and engage in discussions about the integration of NOS with neuroscience?	Observations Protocol Records and Note Taking (large group class sessions)	Integrative Analysis
2. To what extent do pre-service and in-service teachers change their understandings of NOS during a sequence of these opportunities?	SUSSI Survey (pre- and post-class experience)	Coding for Themes
3. How do participants' attitudes and beliefs on the integration of neuroscience and NOS change as they engage in the four-week teacher education intervention on neuroscience and NOS?	Attitudes and Beliefs about NOS-Neuroscience Connections (AB NOS) Survey (large group, including catalytic group members)	Integrative Analysis
4. How do participants in a 4-week neuroscience-based intervention change their understandings of NOS over the course of this intervention?	Attitudes and Beliefs about NOS-Neuroscience Connections (AB NOS) Survey (large group, including catalytic group members)	Integrative Analysis
	MI (large group, including catalytic group members) and FG (only catalytic group members) Reflection Reports	Coding for Themes
	SUSSI Survey (pre- and post-class experience)	Coding for Themes

(continued)

Table 2 (continued)

Summary Table of Research Questions, Sources of Evidence and Analyses

Research Question	Source of Evidence	Analysis
5. Overall, how effective was the catalytic group function in the integration of neuroscience and NOS during the 4-week intervention?	Catalytic group reflection reports	Coding for themes
	Researcher journal	Integrative Analysis
6. How do participants change their perceptions of NOS, neuroscience, and their integration over the course of this intervention?	Attitudes and Beliefs about NOS-Neuroscience Connections (AB NOS) Survey (large group, including catalytic group members)	Integrative Analysis
	MI (large group, including catalytic group members) and FG (only catalytic group members) Reflection Reports	Coding for Themes
	SUSSI Survey (pre- and post-class experience)	Coding for Themes

Role of the Researcher and Ethical Considerations

The participants in the research objective were purposefully selected based on enrollment in a course on the Nature and Practices of Science. Participants were given the opportunity to volunteer in the research objective, as it took place over the course of four class sessions, with two additional one-hour sessions for six willing participants. If students enrolled in the course chose to not engage in the research study, they were encouraged attend class per their normal routine and engage in the discussions that the research assistants observed during the study. Participants who chose to engage in both the large-group sessions and additional catalytic-group sessions were remunerated via waivers from final term project presentations. Neither audio- nor video- taping were used in the present study to grant anonymity to the participants. The reporting of evidence gathered from participants utilized participant numbers to protect their identities.

Pseudonyms were used to carry out the reporting of data collected from this study. A roster of participants' real names, their assigned pseudonyms, and participant numbers were kept on a password-protected computer owned and maintained by the researcher. This roster allowed for accurate dispersal of remunerations for participation.

There were few low-level potential risks in the present study. Participants could have suffered from boredom or fatigue during participation in this study. Additionally, there was a small risk of triggering students' emotions or a sense of discomfort if conversations included discussions about race and diversity in science education. If participants began to feel distressed at any point in time, they were removed from the learning context and university services for health and counseling was suggested to those participants. There were no potential benefits of the research objective. All participants who agreed to engage in the present study signed an informed consent form, listing the potential risks from participation and a description of how the evidence was used in analyses.

The researcher served many roles in the research objective. During all large-group lesson studies, the researcher was a full participant, leading other participants in discussion-based activities. For catalytic-group sessions, the researcher acted as a participant observer, facilitating the discussions as necessary. The researcher has acted as a teaching assistant for the course in prior semesters but did not draw on these experiences during the research objective, removing potential bias in instruction and data analysis. The role was not specifically intervening to promote a particular outcome that would be beyond the normal role of instruction but rather to sustain class interactions and activities. However, the role of the researcher may have influenced the data that was collected for analysis in this study. In particular, the researcher journal was more of a reflective tool rather than in-the-moment observations and thoughts, which could have contributed to the observation rubrics in a manner that was different than the way the researcher journal in formed this study. More generally, the collection of data is often biased by the level of engagement that a researcher has within the researcher space. Because the role of the researcher was quite high in this study, this influenced the data collected for analysis as the context of the study, and thus the data available for collection, can change based on the role of the researcher.

Elements of Rigor

The present study gained rigor through multiple sources of credibility, transferability, and confirmability in the methodology (Boeije, 2009; Lincoln & Guba, 1985). Credibility and transferability was established as the research assistants engaged in persistent observation of the setting, including recordings of the context with rich, thick descriptions via an observation protocol [*Appendix P*]. The process in which the setting and participants was studied was consistent for the duration of the research objective, and any shifts in this study process that affect the context for learning were documented in full. Additionally, there were multiple sources of data to be collected using the research instruments and interviews, increasing credibility of this study. These multiple sources of evidence were triangulated with one another to identify emergent themes in the data, and thus provide evidence of concurrence of the findings (Lincoln & Guba, 1985). This triangulation contributed to the credibility of this study. Lastly, confirmability was established by maintaining a researcher journal and an audit trail, which described in detail the procedures of the study and included the researcher's perspective on how the process worked (Lincoln & Guba, 1985).

Limitations

There are several limitations to this research objective. First, students who enrolled in this course on NOS were not required to also be a student of the science teacher education program, but rather had an interest in or were already teaching science in K-12 science classrooms. Second, students enrolled in this course came from a variety of science content backgrounds, as specialization in a science field was not required to enroll in the course. The participants in this study did not all possess the same bachelor's degree and thus did not have the same background knowledge. Some participants had little or no previous experience in learning neuroscience and could have influenced their participation in the study. Third, time was an important factor to keep in mind during this research process. Participants in this study came from a variety of teaching backgrounds, where some participants were pre-service teachers who have yet to garner experience in the classroom, while others have been teaching in the classroom for a number of years. For pre-service teachers, this course on the NOS occurred in the fall semester of their one-year program. The course was highly theoretical, looking at aspects of the NOS as defined via the research literature, and historically has not had any connection to classroom practice. Additionally, pre-service teachers who served as participants had no experience student-teaching or observing in classrooms. It was the responsibility of both the researcher and the participants to attempt to connect classroom practice to the NOS even prior to student-teaching experiences. Fourth, participants may not have believed that neuroscience can inform instructional practice, as this is a largely disputed aspect of including neuroscience in education. Fifth, I am the sole researcher in this study the facilitator of large-group lectures and discussions, small-group discussions and interviews with participants. Relationships built with participants over the course of the intervention could have biased the data that was collected and analyzed for the research objective.

Chapter 4

RESULTS

Mixed-Methods Study of the Effectiveness of a Neuroscience-Based Professional Development Intervention to Understand the Nature of Science

Abstract

This is a study of 17 participants who were enrolled in a four-week professional development (PD) intervention focused on neuroscience-based teacher education. The goal of this intervention was to explore the potential relationship between neuroscience and the nature of science (NOS). Using a conceptual framework of conceptual change, a mixed-methods analysis was employed to investigate how participants in the PD intervention interact over the course of the four weeks, how their understandings of the NOS and their attitudes and beliefs toward integrating neuroscience and NOS change over time into one cohesive understanding of the NOS. Furthermore, the study was designed to measure change over time, and the effectiveness of a novel design approach for situated NOS instruction. Three major findings were realized from the evidence of this study: (1) previous exposure to the NOS may help students to apply the abstract tenets of NOS to a scientific context, (2) the use of neuroscience as a situated approach for NOS instruction was particularly effective for areas of neuroscience most closely related to teachers' practice, and (3) added time for critical reflection and small-group discourse impacted the perceived importance of the NOS on daily classroom practice. The three findings provide evidence for a meaningful re-design of the novel instructional approach used in this study for further implementation in NOS instruction, with an emphasis on utilizing small-group discussion settings for students to reflect on their changing understandings of the NOS in relation to teacher pedagogy.

Introduction

Developing conceptions of the nature of science (NOS) is considered critical for developing science literacy and effective science pedagogy in the 21st century (National Research Council [NRC], 2011; NGSS Lead States, 2013). As a result, the NOS is largely included in teacher education, at the pre-service and in-service levels, to develop teachers' conceptions of the NOS. Much research indicate that these conceptions of the NOS have a large effect on classroom practice and students' understanding of science and the NOS (Brickhouse, 1990; Irez, 2006; Lederman, 2007; McComas *et al*., 1998; Ryan & Aikenhead, 1992). Science education research suggests that an explicit, reflective approach to teaching the NOS that is embedded in a science context that is familiar to learners (either through media presence or content specialty), is effective in changing teachers' conceptions of the NOS (Abd-El-Khalick, 2001; Abd-El-Khalick & Akerson, 2004; Akerson, Abd-El-Khalick, & Lederman, 2000; Duschl & Grandy, 2013; Lederman, 2007; Pintrich, Marx, & Boyle, 1993; Schwartz & Crawford, 2004). Additionally, research on the use of neuroscience in teacher education has found that appropriate teacher understanding of brain functions has a positive influence on classroom practice (Dubinsky, Roehrig, & Varma, 2013; Roehrig, Michlin, Schmitt, MacNabb, & Dubinsky, 2012). Therefore, situating the learning of the NOS in the context of examples that illustrate how neuroscience can inform classroom practice may provide a more meaningful opportunity for learning about the NOS in teacher education. This opportunity has the potential to benefit the practice of teachers given current evidence from neuroscience education research and the NOS research on fostering effective classroom practice through PD.

There are four research questions as follows:

1. What are the dynamics that characterize the interactions within a science teacher education intervention (a large group setting), when students discuss the integration of neuroscience with the NOS, and how do those dynamics change during a sequence of opportunities to reflect and engage in discussions about the integration of the NOS with neuroscience?
2. To what extent do pre-service and in-service teachers change their understandings of the NOS during a sequence of opportunities to reflect and engage in discussions about the integration of the NOS with neuroscience?
3. How do participants' attitudes and beliefs on the integration of neuroscience and the NOS change as they engage in the four-week teacher education intervention on neuroscience and the NOS?
4. Overall, how effective was the catalytic group function in the integration of neuroscience and the NOS during the 4-week teacher education intervention?

A mixed-methods study was utilized to measure progressive changes in participants' conceptual understandings while enrolled in a four-week teacher education course on the nature of science and neuroscience.

Literature Review

The nature of science (NOS) is concerned with the epistemologies that guide science as a way of knowing the natural world (Abd-El-Khalick *et al.*, 1998; Lederman, 2007). Researchers of the NOS in science education have not come to an agreement on its definition as there are multiple, varied social and cultural influences on such a body of knowledge (Lederman, 2007). However, the most common definition of the NOS in science education is the 'Lederman 7', which define various aspects of the NOS that are accessible to students (Dushl & Grandy, 2013;

Lederman, 2007). Results have shown that both students and teachers have under-developed understandings of the NOS, but that an explicit, reflective approach of teaching the NOS as it is embedded in a scientific context for reflection is an effective curricular strategy for developing conceptions of the NOS (Abd-El-Khalick, 2001; Abd-El-Khalick & Lederman, 2000; Lederman, 2007; Schwartz & Crawford, 2004). Although such an approach has been argued to increase teachers' understandings of the NOS, there is no evidence that yields it a sustained application during classroom practice (Akerson, Morrison, & McDuffie, 2006; Lederman, 1999).

Very few studies have investigated the successes and failures of teaching neuroscience to in-service and/or preservice teachers, despite their interest in learning about the brain (Dubinsky *et al*., 2013; Hardiman, Rinne, Gregory, & Yarmolinskaya, 2012; Roehrig *et al*., 2012). Although teachers are interested in learning neuroscience, they have underdeveloped conceptions of neuroscience and implicit characteristics of the NOS, as they do not understand the nature of scientific experimentation or the ways in which scientific knowledge changes over time (Ferrari, 2011; McCabe & Castel, 2008; Sylvan & Christodoulou, 2010; Weisberg, Keil, Goodstein, Rawson, & Gray 2008). Teachers who have participated in neuroscience-based, professional development workshops, where specific neuroscience concepts were used to inform pedagogy, developed a better understanding of the NOS through an understanding of the scientific process and the nature of experimentation (Roehrig *et al*., 2012). The results of Roehrig *et al.* (2012) were used to established the three, neuroscience content areas for this study: memory, attention, and emotion regulation (Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000; Gilboa, Winocur, Grady, Hevenor, & Moscovitch, 2004; Graziano, P. A., Reavis, R. D., Keane, S. P., & Calkins, 2007; Hopfinger Buonocore, & Mangun, 2000; Ohman, Flykt, & Esteves, 2001; Takashima *et al*., 2006).

Some of the current research on science teacher education includes analyzing reform-oriented professional development (PD), in which teachers are engaged in critical reflection while they develop curricular strategies to improve their own practice (Darling-Hammond & McLaughlin, 1995; Fishman, Marx, Best, & Tal, 2003; Garet, Porter, Desimone, Birman, & Yoon, 2001; Penuel, Fishman, Yamaguchi, & Gallagher, 2007; Putnam & Borko, 2000; Wilson & Berne, 1999). Additionally, pre-service and in-service science teachers often find it more valuable to engage learning experiences that are more tightly integrated with their future practice, such as student-teaching experiences. Reflecting on those experiences provide for a better opportunity for learning than a traditional approach to teacher education (Akerson *et al*., 2006; Kubitsky & Fishman, 2006; NRC, 2000). Thus, it is increasingly common in the research on science teacher education that a situated approach to teacher education is more meaningful and effective for instructors to carry over what they learn to classroom practice (Akerson *et al*., 2006; Putnam & Borko, 2000). For this intervention, a situated approach to learning was utilized in which the context of daily classroom pedagogy informed the ways in which participants developed their ideas on neuroscience, the NOS, and their integration (Brown, Collins, & Duguid, 1989; Wilson & Berne, 1999). Slightly variant from the literature, this study utilized a situated approach in terms of conceptual situation as opposed to a traditional form of physical situation. In other words, participants were not currently engaged in teaching experiences; so, to simulate the contextual practice of teaching, curriculum materials were used to foster critical thinking about classroom practice. This form of conceptual situated learning allows for participants to develop their own practice and tools necessary to act within the community of science teaching (Brown *et al*., 1989; Grossman, Wineburg, & Woolworth, 2001; Handley, Sturdy, Fincham, & Clark, 2006; Pintrich *et al*., 1993). Neuroscience was selected as the scientific context for reflection during the professional development experiences, because it provides a science topic that is addressed currently in the media, making it a familiar science to situate NOS learning (Abd-El-Khalick & Akerson, 2004; Pintrich *et al.*, 1993). Additionally, neuroscience provides a contemporary science story that exemplifies the tenets of NOS in a concrete and explicit manner, as neuroscience is a 'young', constantly evolving field of scientific research. Contemporary science stories are particularly effective for contextualized NOS instruction (Clough, 2006).

Conceptual change was used as a theoretical framework to analyze the evidence collected for this intervention. Conceptual change is a model for understanding the sequential changes that occur when a learner modifies their beliefs about certain phenomena based on challenging forms of evidence (Hewson & Hewson, 1984). According to one of the precepts of a conceptual change model, in order to change one's conception of an entity from the current category that defines it to a new category, the new category must present a more intelligible, plausible, and fruitful conception than the one currently held (Hewson & Hewson, 1984; Pintrich *et al.*, 1993). For a new concept to be intelligible, it must be, at the very least understandable by the learner. This concept must also be plausible, in that it must have visible applications to some set of scenarios (or situations) and it must have a meaningful link to other currently held understandings. Last, this concept must also be fruitful; it must be able to explain said scenarios with conviction. Based on this rationale, the goal in this study is to utilize a conceptual change approach to facilitate NOS instruction, whereby students are encouraged to develop an alternate conception of the NOS as they learn about scientific philosophy from a neurocognitive perspective. Based on the findings of this study, a larger model for an ideal professional development opportunity to teach educationalists about the NOS through its situation in classroom-relevant neuroscience topics.

Methodology

Field Setting and Participants

This study investigated 17 students at a large, northeastern university in the United States. The participants of this study were solicited via enrollment in a graduate level science teacher education course on the NOS. These 17 participants form the 'large' group for this study. This course satisfied a disciplinary requirement for graduate degrees in science education. All participants in this study had a bachelor's degree in a science or applied science field. The institutional IRB approved this study. Eleven students out of the 17 invited students agreed to fully participate in the research study, including completing surveys and reflection written statements outside of class time. These 11 participants form the 'main' group for this study. These documents were collected as sources of evidence and analyzed by the researcher. Of the 11 full participants, there were five males and six females. The demographics for race/ethnicity identities were as follows: seven Caucasian/White participants, two African/African-American/Black participants, and two Asian/Asian-American/Pacific Islander participants.

Additionally, of the 17 students, six students volunteered to participate in out-of-class activities (explained in further detail in the next section). The six catalytic group participants met in triads outside of normal class time in a special role as "catalytic group" members described in the Procedures section. The first triad (Triad 1) consisted of two Caucasian/White Females and one African/African-American/Black Male. Triad 2 consisted of one Caucasian/White Male, one African/African-American/Black Female, and one Asian/Asian-American/Pacific Islander Female.

Procedures

Because use of qualitative and quantitative evidence together provided richer insights through their complementary sources of insight that was obtained in analyzing the students' progress during the professional development lessons, a mixed-methods approach was used in this study.

Professional course structure. Participants in this study were enrolled in a four-week teacher education course. The 17 participants of this course engaged in large-group sessions over the course of four weeks. Figure 1 shows the format of the large-group sessions, and their relationship to the roles of the smaller interceding groups that served as catalytic groups to promote discussion in the larger group meetings.

In the first three large-group sessions, participants discussed three neuroscience topics: (1) Memory, (2) Attention, and (3) Emotion Regulation. Each of the first three large-group sessions followed the same in-class format. First, students engaged in a mini-lecture on the neuroscience topic for the session. Next, students transitioned into a lesson plan analysis where they analyzed prepared lesson plans for aspects of neuroscience and the NOS in small groups. Lastly, participants engaged in large-group discussions of the NOS topic for that session. In the fourth large-group session, students worked in small groups to create lesson plans related to the Next Generation Science Standards.

In addition to the large-group sessions, six volunteers from the original 17 participants met in the catalytic groups. Catalytic groups were small, discussion-based groups who met outside of class time. The purpose of these catalytic group sessions was to provide a more intimate and directed space for the discussion of the connections between neuroscience and the NOS. The goal of the catalytic group was to act as a catalyst in the large group sessions. In other words, the discussions and questions that arose during the catalytic group sessions were designed to act as a catalyst in the large group session, pushing forward the thinking of the large group. These catalytic groups met two times during the intervention: once after Large Group Session 1, and again after Large Group Session 2. Figure 1 illustrates how these catalytic group meetings alternated between Large Group Sessions. During their catalytic group meetings, each of the small groups discussed and prepared to lead the discussion of the connections between neuroscience and the NOS in the subsequent large-group sessions.

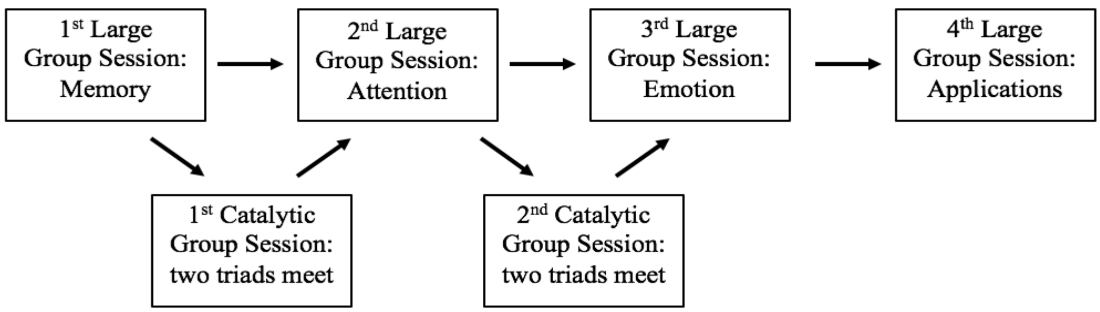

Figure 1: Design of the PD Intervention. Design of the alternating large group and catalytic group sessions showing the integration of catalytic group themes into the larger group lesson setting.

The researcher acted as a full participant in the both the large group sessions and the catalytic group sessions. In the large group sessions, the researcher led the neuroscience mini-lecture and facilitated the discussion-based activities. Facilitation included asking thought-provoking questions to students to encourage establishing connections between the neuroscience and the NOS topics selected for each week, with attention to how those connections manifest in the lesson analysis activity. In the catalytic group sessions, the researcher acted as a facilitator, where statements and/or questions related to the connections between neuroscience and the NOS were used to push the conversations in the small group setting forward.

Sources of Evidence in the study. There are multiple types of evidence collected in this study that are specific to the large-group setting and the catalytic group setting. In the large-group setting, observations were made of the 17 large group participants using the protocol created by the researcher [*Appendix A*]. There were two research assistant observers who were trained in the use of the observation protocol. The reliability of the observations using Cohen's Kappa were *K* (Unweighted) = 0.42 (Content Integration) and K (Weighted) = 0.30 (Discussion Quality). Cohen's Kappa could not be calculated for 'Social Interactions' or 'Ambiance' due to such high levels of agreement, so a frequency of agreements was used. The frequency of agreement for 'Social Interactions' was 92% and the agreements for 'Ambiance' was 94%. Additionally, these 17 participants participated in lesson plan activities that were taken from the BrainU workshops and were analyzed for underlying themes of the NOS, with an emphasis on how neuroscience was presented in the lesson (Roehrig *et al.*, 2012). These lesson plans were analyzed in the first three large-group sessions and each lesson presentation was aligned with the neuroscience topic for the week. Also, a researcher journal was kept that took notes on the dynamics of participants' interactions during the large group sessions and reflected on the quality of the intervention as it progressed overt the four weeks.

Of the 17 students observed in the intervention, 11 of those students were marked as 'main participants'. A 'main participant' status indicates that these 11 students completed surveys and reflection reports outside of class time. The first survey that main participants completed was the Students Understanding of Science and Scientific Inquiry Survey (SUSSI) (Liang *et al.*, 2006). This survey was administered prior to and immediately after the four sessions. The SUSSI survey consisted of both qualitative, open-ended responses and quantitative, Likert-scaled responses that were categorized into six parameters of the NOS (Liang *et al.*, 2006). Additionally, main participants were given the Attitudes and Beliefs about NOS-Neuroscience Connections Survey (AB NOS) once before and once after the four sessions

[*Appendix B*]. This survey was a quantitative, Likert-type survey that was developed by the researcher. Lastly, main participants completed both mid-intervention and post-intervention reflection reports [*Appendix C, D*]. The mid-intervention reflection report was given after the second large-group session, and the post-intervention reflection report was given after the fourth and final large-group session. This reflection report was open-ended, with general prompts regarding the nature of the intervention. The purpose of this reflection report was to allow participants to reflect on their experiences in the intervention.

The six catalytic group participants completed two additional open-ended items that were collected as evidence. These two items included a catalytic group facilitation guide and a catalytic group reflection report. The catalytic group facilitation guide was completed during the one-hour catalytic group meeting. This facilitation guide was open-ended with prompts [*Appendix E*]. The goal of this facilitation guide was to aid the conversations in the catalytic group setting and give space for participants to write down their conversation points from their catalytic group discussions. The facilitation guide was completed once in each catalytic group session for a total of two completed facilitation guides per participant. The second item, the catalytic group reflection report, was completed after the last catalytic group meeting ended. This reflection report was open-ended with specific prompts [*Appendix F*]. Lastly, a researcher journal was used as evidence for the catalytic group setting to mark the statements and dynamics of the discussions in this setting.

Because the research objective included both quantitative and qualitative evidence, multiple types of data analysis were utilized in this intervention. The quantitative data consisted of un-ranked, Likert-scaled items that were given to each participant in a pre-post format. The results were analyzed by examining changes in the percentages recorded for the Likert scale categories from pre- to post-administration. Additional quantitative data included the observation protocol measures. The qualitative evidence was analyzed using NVivo, a qualitative data software that provides evidence of emergent themes based on the text narrative. Open coding was used to establish emerging themes among the qualitative data. Elements of rigor were established in this study by utilizing triangulation, or collecting more than one source of data (i.e., observation protocols, reflection reports, the AB NOS survey, the SUSSI survey, and a researcher journal) in the examination of a social phenomenon, to identify emergent themes (Boeije, 2009). Triangulation of methods also increased the confirmability of the findings by collecting both quantitative and qualitative evidence (Lincoln & Guba, 1985). Consistent, non-participant observations using an established protocol provided rich descriptions of the research setting, increasing the transferability and credibility of the study (Lincoln & Guba, 1985).

Results

The results are addressed for each of the four research questions.

Results for Research Question 1: Dynamics that Characterize the Interactions in the Large Group Setting and the Changes in the Nature of Those Dynamics over Time

The results for the first part of Question 1 are presented for each of the four sessions separately, with the goal of describing the dynamics that characterize the interactions in each of the four sessions. Subsequently, an integrative analysis will be used to describe the second part of research question one to describe the changes in the nature of those dynamics over time.

Observation Protocol. The sources of evidence reported by the two observers are combined and presented in Table 1.

For Session 1 (Table 1), where the lesson topic was neuroscience of memory, the observer evidence indicates that participants were able to integrate the NOS and neuroscience for about half of the session, indicated by a frequency count of 7 for 'yes' (Y) and 7 for 'no' (N) under the heading of 'Content Integration'. Participants uttered largely evaluative statements on the connections between neuroscience and the NOS during Session 1, as indicated by a frequency count of 5 for evaluative (E) statements under a heading of 'Discussion Quality'. There was no evidence from the observations that participants made lower-level cognitive utterances of relationships between neuroscience and the NOS, as indicated by no frequency counts for factual (F), conceptual (C), and analytical (A) statements. There was appreciable evidence of integration of ideas and positive ambiance during Session 1, as indicated by a frequency count of 7 for integrated (I) under 'Social Interactions' and a frequency count of 5 for 'Ambiance'.

Table 1

Total Frequencies for Each Observation Category During the Four Sessions of the Course

Session	Content Integration		Discussion Quality				Social Interactions			Ambiance	
	Y	N	F	C	A	E	S	L	I	P	N
1	7	7	0	0	0	5	0	0	7	5	0
2	4	7	0	3	4	8	0	0	15	15	0
3	1	4	0	2	2	4	0	0	4	8	0
4	0	16	2	12	6	9	0	0	18	17	0

Note. Y = "Yes", N = "No;" F = "Factual", C – "Conceptual", A = "Analytical", E = "Evaluative"; S = "Small Group Members Only", L = "Large Group Members Only", I = "Integrated Interactions"; P = "Positive", N = "Negative". The description of these categories is further presented in *Appendix A.*

In Session 2 (Table 1), where participants learned about the neuroscience of attention, participants did not integrate neuroscience and the NOS for a little over half of the session, as indicated by 7 'no' entries out of 11 total observation entries under the heading of 'Content Integration'. Based on the observations, participants made mid- and high-level discussion statements, as indicated by a frequency of 3 for ‘conceptual’ (C), 4 for ‘analytical’ (A), and 8 for ‘evaluative’ (E) discussion statements. Observations indicated that there was a consistent integrated discussion between small and large group members, as indicated by a frequency observation of zero for both ‘small group only’ (S) and ‘large group only’ (L), and a count of 15 for ‘integrated’ (I) under ‘Social Interactions’. Lastly, the session maintained a positive ambiance for the duration of the session, as indicated by a frequency count of zero for ‘negative’ (N) and a count of 15 under ‘positive’ (P) for ‘Ambiance’.

Session 3 was devoted to a discussion of the neuroscience of emotion and emotion regulation. Session 3 (Table 1) indicated a very low level of integration of neuroscience and the NOS, as illustrated by a frequency count of 1 under ‘yes’ and 4 under ‘no’ for ‘Content Integration’ (Table 1). Discussion statements were mid- to high-level, with a frequency count of 2 for ‘conceptual’ (C), 2 for ‘analytical (A), and 4 for ‘evaluative’ (E) under ‘Discussion Quality’. Social interactions were entirely integrated between small group and large group members, as indicated by a frequency count of zero under ‘small group only’ (S), a count of zero under ‘large group only’ (L), and a count of 4 under ‘integrated’ (I) under ‘Social Interactions’. There was a positive ambiance for the entire duration, as indicated by a frequency count of zero for ‘negative’ (N) and a count of 8 for ‘positive’ (P) under ‘Ambiance’.

Session 4 contained a review of neuroscience topics from the first three sessions, followed by additional time for curricular applications. In Session 4 (Table 1), there was no observation evidence of the integration of neuroscience and the NOS, as indicated by a frequency count of zero for ‘yes’ (Y) and a count of 16 for ‘no’ (N) under ‘Content Integration’ (Table 1). Discussion statements ranged from low-level to mid- and high-level statements, as indicated by a frequency count of 2 for ‘factual’ (F), 12 for ‘conceptual’ (C), 6 for ‘analytical’

(A), and 9 for ‘evaluative’ (E) under ‘Discussion Quality’. Session 4 also contained a relatively robust integrated discussion, as indicated by a frequency count of zero under ‘small group only’ (S), a count of zero under ‘large group only’ (L), and a frequency count of 18 under ‘integrated’ (I). Observation evidence indicated participants maintained positive ambiance between participants occurred during Session 4, with a frequency count of zero for ‘negative’ (N) and a count of 17 for ‘positive’ (P) under ‘Ambiance’.

The evidence in Table 1 illustrates how the pattern of participant behavior in two of the observed categories, ‘Content Integration’ and ‘Discussion Quality’ was inconsistent over the four class sessions. Participants had the most success in integrating neuroscience and the NOS during the first session, which covered the neuroscience of memory. It is possible that ‘Content Integration’ was highest in Session 1 due to the perceived importance and explicit ties that one can make between the neuroscience of memory and teaching and learning. That is, learning about the way memories are formed and accessed brain is one of the neuroscience topics that could be readily applicable to teachers’ practice. Therefore, teachers were inclined to examine the neuroscience material for aspects of the NOS as they related to their own practice. The ability for participants to integrate the neuroscience topics with those of the NOS decreased over the course of the four sessions, with the last session (Session 4) having no indications of content integration. It was interesting to note that despite the lesson study activities that participants engaged in each week where neuroscience and the NOS were implicitly integrated, they struggled to make this integration explicit in the Session 4, where the topic was lesson construction activity.

The observation category ‘Discussion Quality’ was also inconsistent over the duration of the intervention. As shown in Table 1, discussion quality was highest in the first session, and became more expansive to mid-level and low-level discussion statements over the intervention. Session 1 only had ‘evaluative statements’, Sessions 2 and 3 possessed both mid- and high-level statements, and Session 4 possessed all four types of statements. It is interesting to analyze the relationship between discussion statements with the topics discussed during a particular week. For example, the first session discussed memory, a topic most readily applicable to teachers’ practice. Hence, it may have been much easier to make higher level, evaluative statements. The sessions on attention and emotion regulation (Session 2 and Session 3), have ties to teaching and learning, but they are not quite as applicable to curriculum construction, and as a result, participants may have had more difficulty connecting these ideas to classroom practice. The curricular application session (Session 4) exhibited the most variation in discussion statements, indicating a varied level of thinking about neuroscience and the NOS to be applied to writing curriculum. The last two observation categories, ‘Social interactions’ and ‘Ambiance’ were consistent throughout all four sessions of the intervention. This may be because the intervention commenced four weeks after the course started, so participants were familiar with one another and felt comfortable in discussion settings. The majority of participants were also enrolled in the same academic program and were in multiple classes together, increasing their familiarity with one another.

Results for Research Question 2: Changes in Understandings of NOS Over the Intervention

Results regarding changes in understandings of the NOS are separated into qualitative and quantitative evidence that inform the research question. The quantitative, Likert-scale evidence is reported in Table 2. The qualitative evidence is presented as thematic trends identified by analysis of the open-ended responses for each of the five sub-sections of the SUSSI survey. The evidence will be presented sequentially for each of the five subscales in the SUSSI Survey.

Table 2

Pre- and Post-Intervention Survey Responses for SUSSI NOS Survey

Likert-Scale Items.	Pre (D)	Pre (N)	Pre (A)	Post (D)	Post (N)	Post (A)
Observations and Inferences.						
1. Observations may be different because prior knowledge affects observations.	9	0	91	0	0	100
2. Observations will be the same because scientists are objective.	73	9	18	100	0	0
3. Observations will be the same because observations are facts.	100	0	0	91	9	0
4. Scientists make different interpretations based on the same observations.	9	0	91	0	0	100
Change of Scientific Theories.						
1. Theories are subject to revision.	0	0	100	9	0	91
2. Theories may be replaced by new theories in light of new evidence.	0	9	91	0	0	100
3. Theories may be changed because scientists reinterpret existing observations.	0	18	82	0	0	100
4. Theories based on accurate experimentation do not change.	91	9	0	91	9	0
Scientific Theories vs. Laws.						
1. Theories exist in the world and are uncovered through investigations.	27	9	64	45	9	45
2. Laws are not subject to change unlike theories.	45	18	36	45	9	45
3. Laws are theories that have been proven.	64	9	27	64	27	9
4. Theories explain scientific laws.	36	9	55	9	27	64
Social and Cultural Aspects of Science.						
1. Science is not influenced by society and culture because scientists conduct pure, unbiased studies.	73	9	18	100	0	0
2. Cultural values determine what science is conducted and accepted.	9	0	91	9	0	91

(continued)

Table 2 (continued)

Pre- and Post-Intervention Survey Responses for SUSSI NOS Survey

Likert-Scale Items.	Pre (D)	Pre (N)	Pre (A)	Post (D)	Post (N)	Post (A)
Social and Cultural Aspects of Science.						
3. Cultural values determine how science is conducted and accepted.	0	9	91	0	9	91
4. All cultures conduct science the same way because science is universal.	82	9	9	91	0	9
Creativity in Science.						
1. Scientists use their imagination and creativity when they collect data.	27	18	55	18	18	64
2. Scientists use their imagination and creativity when they analyze data.	0	0	100	9	0	91
3. Scientists do not use imagination and creativity because they conflict with logical reasoning.	82	0	18	91	0	9
4. Scientists do not use imagination and creativity because they interfere with objectivity.	91	0	9	91	0	9
Methodology in Scientific Investigations.						
1. Scientists use a variety of methods to produce fruitful results.	0	0	100	0	0	100
2. Scientists follow the same method.	91	9	0	91	9	0
3. When scientists use the scientific method correctly, their results are true.	73	9	18	100	0	0
4. Experiments are not the only means used in the development of scientific knowledge.	9	18	73	0	0	100

Note. D = strongly disagree or disagree, N = neutral, A = strongly agree or agree. First column represents the Likert-items, columns 2-4 represent responses on the pre-test, columns 5-7 represent responses on the post-test.

Observations and inferences. The results for the 11 respondents are reported. With respect to the Likert-scaled evidence on 'observations and inferences' (Table 2), the evidence suggests a developing understanding of how observations and inferences add a layer of subjectivity within the domain of science. The pre-survey evidence shows that 91% of the respondents agreed (A) that observations can be affected by prior knowledge (Item 1), and 91% also agreed that scientists can make different interpretations based on the same observations

(Item 4). There was an interesting contrast for the results of Item 2 in comparison to Item 3. For Item 2 only 73% of participants disagreed that scientific observations are objective; while for Item 3, 100% of participants disagreed that observations are facts. The pre-intervention qualitative evidence showed eight instances of student positions reflecting that observations are guided by past experiences and/or presupposed notions that are based on past experiences. Two participants stated that observations are sensory experiences while inferences are how we make meaning of those observations, where the meaning-making process is driven by past experiences. One participant stated that observations are objective while inferences are subjective and based on a scientists' lens of analysis.

For the post-intervention survey responses in the section on 'Observations and Inferences' (Table 2), the responses to all of the items shifted to a higher level of consensus among participants. All of the participants chose 'Agree' in their responses to Items 1, 2, and 4 (100%), and all but one of the participants responded with a 'Disagree' to Item 3 (91%). The post-survey qualitative evidence had seven instances where respondents described observations as subjective in nature because they include biases from scientists' past experiences. One participant also noted that this bias could come from the current social climate of the scientific community. There was one response that described how observations can be objective if there are low levels of observation, like a plant being blue, but that observations get more subjective as the quality of that observation increases. There were four instances of describing observations as embedded in the five senses; i.e., they described observations as perceptive experiences. All four participants also noted the inherent subjectivity of perception based on past experiences. There were two responses that described how inferences are made based on observations, and four instances that inferences can differ among scientists. One participant noted that this difference comes from culturally constructed ways of thinking that are paradigmatically acceptable and determined by observations.

Change of scientific theories. With respect to ‘change of scientific theories’, the pre-survey evidence (Table 2) shows that participants had an understanding of the tentativeness of scientific theories, as shown by a 100% agreement on Item 1, a 91% agreement on Item 2, and an 82% agreement on Item 3. Additionally, 91% chose ‘Disagree’ to Item 4, indicating that they may have assumed that theories supported at some point in time by accurate experimental evidence never change. In the pre-intervention qualitative responses, all participants stated that theories change over time, although there was variation in the reason for those changes. There were four responses that described how technological advances can give us new information and theories change as a result. There were three references to changes in the culture of science that influence what theories are accepted within ‘normal’ science. There were two instances of describing how theories are built on observations and inferences that are inherently subjective.

In the post-intervention survey (Table 2), the frequency agreement on Items 2 and 3 shifted positively to 100% agreeing that theories can be replaced by new ones and that theories may be changed based on the re-interpretation of evidence. Reponses to Item 4 remained the same after the intervention, while for Item 1, regarding theories are subject to revision, respondents who chose ‘Agree’ decreased slightly to 91%. In the post-intervention qualitative responses, all participants stated that theories change over time, but, similarly, to the pre-intervention survey, there was a large variation in the reasons for those changes as presented in the evidence, and these reasons differed from those in the pre-intervention survey. These reasons for the change in responding to the item about of scientific theories were evident in participants’ descriptions of how these theories change over time; i.e., participants used explanatory statements such as "science changes because ..." and would reference a reason for this change. There were three instances of reference to the Kuhn's idea of scientific revolutions and paradigm shifts, where these shifts are very slow and that scientists are often very resistant to paradigmatic changes. There were three response that described how science changes as culture changes, because theories evolve to the overriding worldview and that science now includes more perspectives of historically marginalized groups. There were four responses that scientific theories change as new ways of thinking or technology emerge.

Scientific theories vs. laws. The pre-survey evidence regarding 'scientific theories vs. laws' show lower levels of agreement among participants (Table 2). A majority (64%) of participants agreed that scientific theories exist in the world (Item 1), and conversely 64% largely disagreed that laws are proven theories (Item 3). A majority of participants (55%) agreed that theories explain scientific laws (Item 4). However, for Item 2 that addressed "laws are not subject to change unlike theories", 45% disagreed. In the pre-intervention qualitative responses, there were 5 responses that laws are mathematical relationships and are unchangeable truth. There were 8 responses that described how theories are tentative and their role is to explain the natural phenomena embedded in a law. There were six responses that laws predict what happens while theories explain why those phenomena occur. There were two responses that described how laws are more observable and thus more universally agreed upon and less changeable.

In the post-intervention survey (Table 2), there was a lower degree of agreement (45%) on Item 1, that theories exist in the world and are uncovered through scientific investigations. Additionally, there was a higher degree of agreement, changing from 36% to 45%, that laws are not subject to change (Item 2), and that theories explain scientific laws, changing from 55% to 64% (Item 4). However, most of the participants maintained their perspective that laws are not proven theories (Item 3). There was also a shift away from 'Agree' (Item 3) going from 27% in the pre-survey to 9% in the post-survey, with an increase in 'neutral'. It is interesting to note how more participants agreed with the explanatory nature of scientific theories (Item 4), but did not shift their stance on the tentativeness of scientific laws (Item 2). In the post-intervention qualitative responses, there were 6 responses that described how laws are mathematical relationships but do not explain how things work. There were nine responses that laws are based on observations, while theories provide inferences and/or hypotheses about laws. There was one instance that laws have enough evidence to be true whereas theories are only plausible, and one instance that natural events are explained by theories but are ultimately dictated by laws.

Social and cultural aspects of science. The pre-intervention survey evidence indicated that participants had a strong understanding of social and cultural influences on science prior to this intervention (Table 2). The majority of participants (91%) agreed that cultural values determine what science is accepted and how science is conducted (Items 2 and 3). Additionally, 73% chose 'Disagree' for Item 1; i.e., that science is influenced by society and culture. Moreover, 82% chose 'Disagree' for Item 4, that science transcends culture and is universal. In the pre-intervention qualitative evidence, there were two instances of recognition that science has its own culture with a reciprocal relationship to the culture of Westernized society. There were four responses that the larger society (outside of science) and the government influence the funding that ultimately drives science and science research. There was one response that the needs of society, such as the cure for cancer or healthcare benefits, drive science research.

In the post-intervention survey (Table 2), responses maintained an agreement of 91% on Items 2 and 3, while responses to Item 1 shifted from 73% to a 100% 'Disagree' response to Item 1; and from 82% to 91% 'Disagree' for Item 4. The post-intervention qualitative responses had four responses that described how the government, private enterprises, and ultimately capitalism only fund and publish science that, in their opinion, is meaningful and relevant to society. There were three responses that science is done based on what is demanded and/or needed by society. There was one instance of describing science as grounded in human society because it is influenced by it; i.e., human observance is biased by demographic identity and science is shaped by the values and attention of the society around it. There were four responses that science is influenced by culture, because it is a human practice; where those at the forefront of science embody Western ideals. There were two responses that described how science depends on the culture being practiced. There was one instance of describing how if science is considered an art, then one of the goals of art, and thus science, is to push the boundaries acceptable within a culture.

Creativity in science. With respect to 'creativity in science' (Table 2), the pre-survey evidence indicated that the majority of participants disagreed with Item 3 (82%), and also Item 4 (91%), that scientists do not use imagination or creativity in science because they could interfere with objectivity or logical reasoning. Participants were unsure of the role of imagination of creativity in collecting data, with only 55% choosing 'Agree' for Item 1, while all participants believed that scientists used imagination and creativity in analyzing data (Item 2). The pre-intervention qualitative responses had four responses that described how creativity and imagination in science occur when the scientist interprets results, where the goal is to come up with something significant that will be published in the community. There were two instances of describing imagination in science as necessary to imagine scientific systems using visuospatial thinking. There was one instance of a response that imagination and creativity are normal functions of the brain that cannot be separated from logic. There were three instances of responses that scientists use imagination and creativity, but it is based on their prior knowledge and thus leads to bias.

In the post-intervention survey (Table 2), responses to Item 1 increased to a 64% agreement, while responses to Item 2 slightly decreased to 91% agreement. For Item 3 there was a small shift toward a higher percentage who chose 'Disagree'; i.e. that creativity influences logical reasoning. Responses to Item 4 did not change. It is interesting to note diversity of responses among participants to Item 1 in both the pre- and post-surveys, regarding the influences of creativity and imagination on data collection, while notable percentages in all three categories of options (D, N, and A). To the contrary, there is a very high level of agreement of the influence of creativity on data analysis (Item 2). It is also interesting to note that the respondents maintained a sustained belief on the lack of interaction between the use of imagination and creativity and scientists' logical reasoning. In the post-intervention qualitative responses, there were four responses that imagination and creativity are the catalyst for scientific revolutions, where they are the tools scientists can use to solve the puzzles of normal science and move into new paradigms when the old paradigm begins to collapse. There were three instances of describing creativity and imagination as a part of the scientific inquiry process, which is creative in nature. There was one response that described how imagination and creativity are necessary to make inferences from observations, and there was one instance that described how it is impossible to separate imagination and creativity from the act of doing science.

Methodology in scientific investigations. The pre-survey evidence on 'methodology of scientific investigations' (Table 2) indicated high levels of agreement on Items 1 (100%) and 2 (91%), that scientists use a variety of methods to carry out scientific investigations. The majority of participants (73%) agreed that experiments are not the only valuable method to carry out science (Item 4). However, a majority of the participants disagreed with Item 3, that following the scientific method will give accurate results. The pre-intervention qualitative evidence had six instances of describing how science is evidence-based inquiry and has different requirements for different sub-paradigms of science, and thus, it would be inappropriate to use one method across the board. There were two responses that described how there is a scientific method, but it has flaws because it is based on Western ideals of science, and often times different types of scientists focus on different aspects of that method. There was one response that described how science has a multitude of methods but they all follow a universal rule of being logical and scientific. There was one response that described how humans are incapable of carrying out the perfect experiment, so no two methods are ever truly the same.

In the post-intervention quantitative evidence (Table 2), all participants agreed with Items 1 and 4, that scientists use a variety of methods and that experiments are not the only valuable method to develop scientific knowledge. Additionally, all participants disagreed that following the scientific method gives true and accurate results (Item 3), and a majority of participants (91%) disagreed that scientists follow the same method (Item 2). It is interesting to note that after the intervention there was a positive shift in participants' belief that the scientific method is not the most valuable in providing true results and that scientists do not always follow the same method. In the post-intervention qualitative evidence, there were ten instances of responses asserting that science has many different methods, although there were variations in the reasons offered by the respondents for those different methods. There were eight instances of responses that science is influenced by culture and society, which influences the methods that each scientist will use. There was one instance of a respondent who declared, "Because imagination and creativity are inherent in science, scientists cannot follow a single method." There was one instance where a respondent stated that different methods are used to gather data. And there was one instance of a comment that Earth Science lacks almost all of the scientific method, but still produces meaningful science. There was one instance of a response that scientists use the scientific method to collect evidence related to a hypothesis that either supports or contradicts a theory.

Results for Research Question 3: Changes in Attitudes and Beliefs Towards the Integration of Neuroscience and NOS Over the Course of the Intervention

The results for the AB NOS survey are presented in Table 3.

Table 3

Main Frequencies of Responses for AB NOS Survey

Likert-Scale Items.	Pre (D)	Pre (N)	Pre (A)	Post (D)	Post (N)	Post (A)
1. Using examples from neuroscience research can be a good context for understanding the nature of science.	0	18	82	0	27	73
2. It may be easier to make connections between NOS and neuroscience if a teacher knows more about the neuroscientific domain.	0	27	73	0	0	100
3. Neuroscience and NOS are disparate scientific endeavors and bear few obvious connections to one another.	73	18	9	91	9	0
4. I am interested in the integration of NOS and neuroscience to better understand NOS concepts	0	0	100	0	18	82
5. I believe that it is necessary to learn NOS to be an effective science educator.	9	0	91	9	0	91
6. It is possible to explain NOS concepts using evidence from the neurosciences as scientific examples.	0	45	55	0	9	91
7. There is a meaningful and logical relationship between neuroscience and NOS.	0	27	73	0	18	82
8. The many qualities of NOS are an excellent resource that should be used to better understand how scientific knowledge is developed and evolves over time.	0	9	91	0	0	100

(continued)

Table 3 (continued)

Main Frequencies of Responses for AB NOS Survey

Likert-Scale Items.	Pre (D)	Pre (N)	Pre (A)	Post (D)	Post (N)	Post (A)
9. I believe that it is valuable to learn the various historical and philosophical aspects of NOS.	0	9	91	0	9	91
10. Applying NOS principles to a science discipline that we teach is useful for developing a holistic understanding of NOS.	0	0	100	0	0	100
11. I find learning about NOS to be a rewarding experience.	0	0	100	0	0	100
12. In my opinion, learning about NOS can enhance my understanding of a science domain.	0	0	100	0	0	100
13. I feel more confident in including neuroscience and NOS in my teaching.	--	--	--	9	18	73
14. By participating in this part of the course, I found it useful to think about integrating neuroscience ideas with NOS as a way of clarifying the meaning of NOS.	--	--	--	9	27	64
15. I believe that students would be positively attracted to learning science when neuroscience and NOS are integrated, based on what I learned so far.	--	--	--	18	18	64
16. Many features of NOS can be identified and exemplified in neuroscience.	--	--	--	0	18	82
17. I would recommend that someone attempting to learn NOS could use some aspects of neuroscience to increase their understandings.	--	--	--	9	9	82
18. As a result of this course, neuroscience has helped me to see NOS from a different perspective.	--	--	--	0	9	91

Note. D = strongly disagree or disagree, N = neutral, A = strongly agree or agree. First column represents the Likert-items, columns 2-4 represent responses on the pre-test, columns 5-7 represent responses on the post-test.

In the pre-intervention survey, participants felt very strongly toward the importance and utility of the NOS in science teaching and learning. Ninety-one percent agreed that it was necessary to learn the NOS to be an effective science educator (Item 5), 91% agreed that the qualities of the NOS are a good resource to better understand how scientific knowledge develops over time (Item 8), and 100% agreed that learning about the NOS enhances their understanding of science (Item 12). Additionally, 100% of participants believed that applying the NOS to a domain that they teach would be effective for developing a holistic understanding of NOS (Item 10). In the post-intervention survey, participants maintained many of their beliefs on the importance of the NOS for science teaching and learning. Responses to Items 5, 9, 10, 11, and 12 remained the same, while for Item 8, that the qualities of the NOS inform how scientific knowledge evolves, the responses increased to 100% 'agree'. Although participants' perspectives did not change drastically over the intervention, they maintained their belief that the NOS is important and has a sustained value in science and science education.

The pre-intervention survey questions that targeted perspectives on the integration of neuroscience and the NOS (Table 3) indicated that 82% of participants agreed that neuroscience can be a good context for understanding the NOS (Item 1). 73% of participants also agreed that it may be easier to make connections between neuroscience and the NOS if one is more familiar with neuroscience (Item 2). All participants indicated an interest in learning about the integration of neuroscience and the NOS (Item 4) and 73% disagreed that neuroscience and the NOS are disparate scientific endeavors (Item 3). Lastly, 73% of participants thought that there was a meaningful relationship between neuroscience and the NOS (Item 7) and 91% agreed that the NOS could be explained using neuroscience examples (Item 6). In the post-intervention survey, 91% of participants disagreed with Item 3, that neuroscience and the NOS are separate scientific endeavors. Additionally, a higher number of participants agreed with Items 6 (91%) and 7 (82%), that there is a meaningful relationship between neuroscience and the NOS where the NOS can be explained using neuroscience examples. After the intervention, all participants agreed that it would have been easier to make connections between neuroscience and the NOS if they were more familiar with neuroscience content (Item 2), and concomitantly their interest in the integration of neuroscience and the NOS decreased to 82% (Item 4). As a result of the intervention, participants changed their perspectives on the utility of connecting NOS to neuroscience and found that many examples of the NOS can be found in neuroscience (Item 6). Participants felt as though this integration would have been easier if they were either more familiar with neuroscience (Item 2) or were connecting the NOS to their own subject matter expertise (Item 10).

Questions 13-18 of the AB NOS survey (Table 3) were administered after the intervention, because they involve responses to the experiences of the intervention. The results of these questions indicated that the majority of participants (91%) found that the intervention helped to change their perspectives of the NOS (Item 18), and 82% of the participants would recommend using neuroscience to better understand the NOS (Item 17). Additionally, the majority of participants (82%) thought that many features of the NOS could be exemplified in neuroscience (Item 16), and as a result of the intervention 73% of participants felt more confident using the NOS and neuroscience in their teaching (Item 13). Lastly, 64% of participants found the integration of neuroscience and the NOS to be useful in clarifying the subjective meaning of the NOS (Item 14). It is interesting to note how participants found neuroscience to be useful to clarify the NOS generally, and felt that this integration was helpful enough to recommend it to someone who was learning the NOS.

Research Question 4: The Effectiveness of the Catalytic Group Function in the Integration of Neuroscience and NOS

The objective of using the catalytic group in the research objective was to stimulate a more integrated discussion on neuroscience and the NOS. The integration of neuroscience and the NOS theoretically would include discussions on the validity of neuroscience findings as 'truthful' or 'objectively correct and unchanging' in addition to evaluating how those findings came to be and what aspects of the NOS (sociocultural, subjectivity, etc.) influence the findings but are not apparent in the way we perceive those findings. Each catalytic group met twice over the course of the intervention to have these discussions and prepare 'take-away' points and discussion questions to share with the larger group in the subsequent session. The results of the function of the catalytic group are presented in a stepwise fashion.

Small-group discussions. Evidence from catalytic group participants' reflection reports indicated three thematic trends related to their discussions in catalytic groups and their attitudes toward sharing these discussions with the larger class. There were three instances where catalytic group participants indicated that the small group discussions were more productive, because the small group was more intimate; all members of the small group had a voice. The feeling of having a larger voice allowed participants to reflect on their own perspectives and not just that of the teacher.

The second thematic trend indicated that the small group discussions were more cohesive and had a fluid progression in comparison to the larger group setting. There were three instances where participants described how the it was nice to sway the conversation where they thought it should go, and that this was possible especially because they felt they had a larger voice in the small group setting. One participant described how conversations seemed to wander but in a really productive way that was actually helpful in that they got the opportunity to interrogate their own thoughts. One participant described how the opportunity for reflection in the small group allowed for a more cohesive discussion that was not too radically split by opposing viewpoints.

The last thematic trend described how the small group was a better environment to break things down and reflect on the NOS at a larger level. One participant described how the large group fostered topics for discussion in the small groups, where the small groups allowed for a deeper understanding of the material to be laid down. Two participants described how having the chance to reflect on their own thoughts in the small group gave them a clearer picture of how they would use NOS in the classroom. One participant described the benefit of the small group as providing a context for examining the NOS as a whole, with neuroscience still providing a grounding subject. This participant noted how an analysis of the NOS from a big picture perspective was not something they had a chance to reflect on in the larger group setting.

Planning and function of catalytic group in large group sessions. A small amount of evidence from participants' reflection reports described attitudes toward sharing out their discussion points or ideas from the small group discussions in the larger group setting. Despite having explicit time for planning out what items would be taken back to the large group setting for a share-out, catalytic group members felt negatively on sharing out the discussion points from their small group experiences. There were two instances where participants described how they were unsure of taking their ideas from the smaller group back to the large group setting, unless it was a topic that they felt strongly about or had confidence expressing. There was one instance where a participant described how there was not as much overlap in the discussions that took place in the small group versus the large group setting, so it did not feel like the appropriate space to share any discussion points from the small group discussions. However, this participant felt as though their participation in the small group positively affected how willing they were to speak up during the large class meetings because they felt as though their opinions were validated in the smaller groups.

Evidence from the researcher journal further describe how participants were reluctant to share out their small group discussion points, despite planning for them during focus group meetings. At the beginning of Sessions 2 and 3, there was explicit time set aside for small group discussion points to be shared. However, catalytic group members were reluctant to share out their own ideas, and instead, the researcher summarized the main points from each small group discussion. In Session 3, large group participants asked questions to clarify some points that were made in the small group discussions, to which the catalytic group members responded to those questions. As a result, the planning activities were not effective in helping catalytic group members to share out their discussion points and did not influence the discussions in the large group setting, but they did affect the confidence and willingness to participate in large group activities.

Overall effectiveness of this novel design. The goal of the catalytic group in the novel design as shown in Fig. 1 was to encourage forward thinking about how to synthesize neuroscience and the NOS in a way that concretizes the abstract meaning of the NOS. The way in which this goal should have been realized was for the catalytic group members to plan the points and develop questions that they wish to share with their classmates regarding their small-group discussions, stemming a larger discussion in the large group lesson setting. However, based on the results from the catalytic group on perceptions toward sharing their discussion points, this goal was not realized in an effective manner that stimulated increased conversation about the connections between neuroscience and the NOS in the large group setting. Participants created cohesive take-away points that the researcher used to guide some discussion in the large group setting, but catalytic group participants did not develop discussion questions for use in the large group setting. This goal of developing questions for use in the large group lesson setting may not have been clearly communicated to participants during the catalytic group sessions. Despite the small group participants' lack of meeting the goal of fostering a broader discussion between neuroscience and the NOS, there were several other meaningful benefits that the catalytic group members gained as a result of their experiences in the small group discussions. These benefits included increased confidence in participating in the large group lesson setting during discussion-based activities that were not related to sharing out their experiences to the small group discussions and having a larger voice for discussion in the small group setting which contributed to gaining a clearer understanding of the NOS.

Discussion

The objective of this research represents a socially constructed approach to the NOS instruction that resulted in evidence that describes the ways in which the integration of neuroscience and the NOS benefits NOS instruction. The results for each research question as it was presented in the foregoing Results section can be synthesized with the theory of conceptual change to develop a better understanding of participants' intellectual interactions with the neuroscience-based PD intervention. From the results, there are three important findings that can be considered when attempting to use neuroscience as a situated context to better understand the NOS. First, having some previous experience learning the tenets of NOS may have given participants a less abrasive transition into applying the NOS to a scientific context. This previous understanding allowed for a deeper understanding of the NOS. Second, the use of a neuroscience context was plausible, intelligible, and fruitful for the specific area of neuroscience that applies to teachers' practice. Lastly, participants in the study valued having time for critical reflection and discourse in small-group settings. In particular, when discussants are encouraged to share their own science experiences and make connections to the NOS, there exists a perceived value by participants and an impact on participants' perceived utility of the NOS on teacher pedagogy. In other words, when students have the opportunity for critical reflection, they were able to see the power of using the NOS in their own classrooms, as it informed their own understandings of the scientific enterprise

The participants in this intervention have previously received an introduction to the NOS over the span of five weeks, just prior to the commencement of this PD intervention. In this way, it is logical that the results for Research Question 2 were not colored with such a stark contrast as the results of other sections, because they have previously encountered the anomaly of understanding the NOS as a subjective experience that did not align with their previous conceptual ecology. When this teacher education course commenced, participants were in the midst of reshaping their perspectives on the NOS, and thus were very interested in the ways in which neuroscience and the NOS may be connected to one another. Initially, fewer participants believed in the utility of making the connection between neuroscience and NOS, thinking that they were disparate scientific endeavors. As a result of the intervention, a vast majority of participants were able to see the meaningful relationship between neuroscience and the NOS, thereby changing their views of the NOS with respect to the way scientific theories can change over time, how science is colored by subjectivity starting at the personal level of the scientist through observations and continuing to a broader level of cultural and societal impacts on science. Thus, participants fostered a deeper understanding of the NOS and saw the utility of applying the NOS to a scientific context to better understand its abstract nature.

The use of neuroscience as foundation or scientific context to understand the complex and the abstract NOS had perceived intelligibility, plausibility, and fruitfulness by the participants in this research objective. That is, participants found that neuroscience was useful to help explicitly describe what the theory of the nature of science (in its multiple forms) is saying, and that participants were able to interpret their experiences in and knowledge about science through this new conception of the connections between neuroscience and the NOS. However, not all of the neuroscience topics covered in the research objective had this similar utility for participants. That is, this idea of using their new-found conceptions of neuroscience and the NOS was most productive and meaningful when participants were talking about neuroscience of memory, and it was less productive and more difficult for participants to synthesize their own perspectives with neuroscience of attention or emotion regulation.

Participants in the catalytic group may have benefitted the most from this research objective in that because they were allotted more time for critical reflection and meta-cognitive discourse on the connections between neuroscience and the NOS and on the NOS, generally. This time allowed for the catalytic group participants to develop more concrete and explicit ideas of how the NOS can explain the domain of neuroscience, how the NOS can be applied to scientific domains in general to better understand how these domains operate, and how the NOS could be used in the classroom. These discussions also gave catalytic group participants an increased confidence in engaging in the NOS discussion-based activities in the large group lesson setting. The small and intimate setting that described the catalytic group discussions allowed all participants of those discussions to have a voice. In this group, they could share their own science experiences and connect them to the NOS in a discourse-like format. The catalytic group setting gave some participants an intimate yet structured opportunity to apply what they learned about the NOS to their own scientific understanding, allowing them to develop deeper understandings of the NOS.

Areas for future research related to this intervention include investigating the appropriateness of using multiple areas of neuroscience as a context for teachers to better understand the NOS. Clough (2006) found that students can be blocked to the NOS development by unfamiliar science content, and that this issue of familiarity can be mitigated through contemporary science stories that are presented in the media. Neuroscience of memory is one of the most common and easily applicable areas of neuroscience to relate to teacher pedagogy, and in this intervention, participants had more success in integrating neuroscience of memory with the NOS. It may be useful to use neuroscience of memory as the grounding context for teachers' understanding of the NOS, and as teachers gain familiarity with the domain of neuroscience they can then learn more about other areas of neuroscientific research.

Additionally, attention to the cognitive factors that influence the motivation to learn a topic that requires a conceptual change approach such as the NOS is necessary for helping students to successfully integrate the NOS with their own knowledge of science. Pintrich *et al.* (1993) describe two cognitive factors, meta-cognitive reflection and self-questioning, that played a large role in the successful discourse that occurred between catalytic group participants. Those participants were given the space to be explicit about the prior knowledge they possessed about science that could have negatively affected their ability to integrate their scientific knowledge and perceptions with the NOS and neuroscience. Abd-El-Khalik and Akerson (2004) also describe how a deep processing orientation is a cognitive factor that allowed students to develop more elaborate views of the NOS. Those who consistently seek to clarify the meaning of the NOS and apply it to multiple contexts while monitoring their own self-learning are considered to be 'deep learners'. It is possible that those who volunteered for the catalytic group may have been deep learners as they possessed a need for clarifying the NOS that was great enough to justify spending out-of-class time with other participants to gain a better understanding of the NOS.

Lastly, motivational factors for learning, such as an intrinsic commitment to learn and the perception of oneself as a successful learner, may affect the perception of the utility of neuroscience as a way to understand the NOS. These motivational factors may also play a role in perceptions of how useful neuroscience is as a grounding context for understanding the NOS. In this PD intervention, a vast majority found the NOS to be important and necessary for better understanding science and being an effective science educator, but these beliefs did not always relate to a positive motivation or viewpoint toward using neuroscience as a context for understanding the NOS. NOS instruction prior to this intervention was presented in a decontextualized fashion, so when the intervention commenced there most likely was a lower level of motivation for applying the NOS to any science context, not just neuroscience. Abd-El-Khalik and Akerson (2004) suggest that motivation can play a very large role in the conceptual change process for the NOS, and thus, it is important to interrogate students' attitudes toward the utility of using a scientific context for understanding the NOS. Additionally, it may be necessary to use a scaffolded approach to including students' personal science experiences as a method for a highly contextualized approach to NOS instruction. Clough (2006) suggests that such a highly contextualized approach is very effective for seamlessly understanding science content and the NOS.

Conclusion

This study investigated the utility of a PD intervention that was focused on the integration of neuroscience and the NOS as an alternative model for NOS instruction. Research in teacher education illustrates the importance of including the NOS in science teacher preparation in that it has a positive impact on teachers' practice (Abd-El-Khalick, 2001; Abd-El-Khalick & Lederman, 2000; Abd-El-Khalick, Bell, & Lederman 1998; Akerson, Abd-El-Khalick, & Lederman, 2000; Bell, Lederman, & Abd-El-Khalick, 2000; Irez, 2006; Koenig, Shen, and Bao, 2012; Lederman, 2007; Ryan & Ikenhead, 1992; Schwartz, Lederman, & Crawford, 2004). Additionally, research on the utility of neuroscience in teacher education shows that neuroscience also positively impacts teachers' practice, with an increased impact on teachers' ability to implicitly include the NOS in their own teaching (Bernardon, 2013; Dubinsky, 2010; Dubinsky, Roehrig, & Varma, 2013; Roehrig, Michlin, Schmitt, MacNabb, & Dubinsky, 2012). This study found that the integration of neuroscience and the NOS also positively affects teachers' practice. This positive influence is exemplified in how participants' understandings of the NOS became more developed and eloquent as a result of this intervention. Neuroscience was especially useful in helping participants to construct more develop understandings of the NOS, given its tentative and subjective nature as a contemporary science story. Future use of this approach may include an alteration, where all participants meet in small groups and develop discussion questions that they can bring back to the large group setting. In these small group meetings, explicit attention should be given to creating explicit discussion questions for larger group sessions, as this allows for a more balanced, socially constructed meaning of the NOS to develop in the large group. Additionally, more time in the larger group should be devoted to discussion questions that arose in these small group settings, using the information, opinions, and personal beliefs of participants to push forward the discussion in the large group setting. Opportunities for critical reflection and discussion that characterized the catalytic group lesson setting was important in helping catalytic group members to develop a more cohesive understanding of the NOS.

References

Abd-El-Khalick, F. (2001). Embedding nature of science instruction in preservice elementary science courses: Abandoning scientism, but... *Journal of Science Teacher Education*, *12*(3), 215-233.

Abd-El-Khalick, F. & Akerson, V. L. (2004). Learning as conceptual change: Factors mediating the development of preservice elementary teachers' views of the nature of science. *Science Education*, *88*(5), 101-143. doi: 10.1002/sce.10143

Abd-El-Khalick, F., & Lederman, N. G. (2000). The influence of history of science courses on students' views of nature of science. *Journal of Research in Science Teaching*, *37*(10), 1057-1095. doi: 10.1002/1098-2736(200012)37:10<1057::AID-TEA3>3.0.CO;2-C

Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education*, *82*(4), 417-436.

Akerson, V. L., Morrison, J. A., & McDuffie, A. R. (2006). One course is not enough: Preservice elementary teachers' retention of improved views of nature of science. *Journal of Research in Science Teaching*, *43*(2), 194-213. doi: 10.1002/tea.20099

Boeije, H. (2009). *Analysis in qualitative research*. Thousand Oaks, CA: Sage.

Brickhouse, N. W. (1990). Teachers' beliefs about the nature of science and their relationship to classroom practice. *Journal of Teacher Education*, *41*(3), 53-62.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated Cognition and the Culture of Learning. *Educational Researcher*, *18*(1), 32–42.

Clough, M. (2006). Learners' responses to the demands of conceptual change: Considerations for effective nature of science instruction. *Science Education*, 15(1), 463-494.

Corbetta, M., Kincade, J. M., Ollinger, J. M., McAvoy, M. P., & Shulman, G. L. (2000). Voluntary orienting is dissociated from target detection in human posterior parietal cortex. *Nature Neuroscience*, *3*(3), 292-297.

Creswell, J. W. (2012). *Qualitative inquiry and research design: Choosing among five approaches.* Thousand Oaks, CA: Sage.

Darling-Hammond, L. & McLaughlin, M. W. (1995). Policies that support professional development in an era of reform. *Phi Delta Kappan*, *76*(8), 597.

Dubinsky, J. M., Roehrig, G., & Varma, S. (2013). Infusing neuroscience into teacher professional development. *Educational Researcher, 42*(6), 317-329.

Duschl, R. A. & Grandy, R. (2013). Two views about explicitly teaching nature of science. *Science and Education*, *22*(9), 2109 – 2139.

Ferrari, M. (2011). What can neuroscience bring to education? *Educational Philosophy and Theory*, *43*(1), 31-36. doi: 10.1111/j.1469-5812.2010.00704.x

Fishman, B. J., Marx, R. W., Best, S., & Tal, T. R. (2003). Linking teacher and student learning to improve professional development in systemic reform. *Teaching and Teacher Education*, *19*, 643-658. doi: 10.1016/S0742-051X(03)00059-3

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, *38*(4), 915-945.

Gilboa, A., Winocur, G., Grady, C. L., Hevenor, S. J., & Moscovitch, M. (2004). Remembering our past: Functional neuroanatomy of recollection of recent and very remote personal events. *Cerebral Cortex*, *14*(11), 1214-1225. doi: 10.1093/cercor/bhh082

Graziano, P. A., Reavis, R. D., Keane, S. P., & Calkins, S. D. (2007). The role of emotion regulation and children's early academic success. *Journal of School Psychology*, *45*(1), 3-19. doi: 10.1016/j.jsp.2006.09.002

Grossman, P., Wineburg, S., & Woolworth, S. (2001). Toward a theory of teacher community. *The Teachers College Record*, *103*, 942-1012.

Handley, K., Sturdy, A., Fincham, R., & Clark, T. (2006). Within and beyond communities of practice: Making sense of learning through participation, identity and practice. *Journal of Management Studies*, *43*(3), 641-653. doi: 10.1111/j.1467-6486.2006.00605.x

Hardiman, M., Rinne, L., Gregory, E., & Yarmolinskaya, J. (2012). Neuroethics, neuroeducation, and classroom teaching: Where the brain sciences meet pedagogy. *Neuroethics*, *5*(2), 135-143.

Hewson, P. & Hewson, M. (1984). The role of conceptual conflict in conceptual change and the design of science instruction. *Instructional Science, 13*(1)*,* 1-13.

Hopfinger, J. B., Buonocore, M. H., & Mangun, G. R. (2000). The neural mechanisms of top-down attentional control. *Nature Neuroscience*, *3*(3), 284-291. doi: 10.1038/72999

Irez, S. (2006). Are we prepared? An assessment of preservice science teacher educators' beliefs about nature of science. *Science Education*, *90*(6), 1113-1143. doi: 10.1002/sce.20156

Kubitskey, B., & Fishman, B. J. (2006, June). A role for professional development in sustainability: Linking the written curriculum to enactment. In *Proceedings of the 7th International Conference on Learning Sciences* (pp. 363-369). International Society of the Learning Sciences, Bloomington, IN.

Lederman, N. G. (1999). Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. *Journal of Research in Science Teaching*, *36*(8), 916-929.

Lederman, N. G. (2007). Nature of science: Past, present, and future. In S.K. Abell & N. G. Lederman, (Eds.), *Handbook of Research on Science Education* (pp. 831-879). Mahwah, NJ: Erlbaum.

Liang, L. L., Chen, S., Chen, X., Kaya, O. N., Adams, A. D., Macklin, M., & Ebenezer, J. (2006, April). Student Understanding of Science and Scientific Inquiry (SUSSI): Revision and further validation of an assessment instrument. Paper presented at the *Annual Conference of the National Association for Research in Science Teaching*, San Francisco, CA.

Lincoln, Y.S. & Guba, E.G. (1985). *Naturalistic Inquiry*. Thousand Oaks, CA: Sage.

McCabe, D. P. & Castel, A. D. (2008). Seeing is believing: The effect of brain images on judgments of scientific reasoning. *Cognition*, *107*, 343-352. doi: 10.1016/j.cognition.2007.07.017

McComas, W. F., Clough, M. P., & Almazroa, H. (1998). The role and character of the nature of science in science education. In W.F. McComas (Ed.), *The nature of science in science education: Rationales and Strategies* (pp. 3–39). Dordrecht, Netherlands: Springer.

National Research Council [NRC]. (2000). Teacher learning. In J.D. Bransford, A. L. Brown, &. R.R. Cocking (Eds.), *How people learn: Brain, mind, experience, and school: Expanded edition* (pp. 190–205). Washington, DC: National Academies Press.

National Research Council [NRC]. (2011). *A framework for k-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

NGSS Lead States (2013). *Next Generation Science Standards, for States, by States*. Washington DC: National Academy Press.

Ohman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology*, *130*(3), 466-478. doi: 10.1037/0096-3445.130.3.466

Penuel, W. R., Fishman, B. J., Yamaguchi, R., & Gallagher, L. P. (2007). What makes professional development effective? Strategies that foster curriculum implementation. *American Educational Research Journal*, *44*(4), 921-958.

Pintrich, P., Marx, R., & Boyle, R. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 63*(2), 167-199.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning?. *Educational Researcher*, *29*(1), 4-15.

Roehrig, G. H., Michlin, M., Schmitt, L., MacNabb, C., & Dubinsky, J. M. (2012). Teaching neuroscience to science teachers: Facilitating the translation of inquiry-based teaching instruction to the classroom. *Cell Biology Education - Life Sciences Education*, *11*(4), 413-424. doi: 10.1187/cbe.12-04-0045

Ryan, A. G., & Aikenhead, G. S. (1992). Students' preconceptions about the epistemology of science. *Science Education*, *76*(6), 559-580.

Schwartz, R.S., & Crawford, B. A. (2004). Authentic scientific inquiry as context for teaching nature of science. In L. Flick & N.G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education* (pp. 331-355). Dordrecht, Netherlands: Springer.

Sylvan, L. J., & Christodoulou, J. A. (2010). Understanding the role of neuroscience in brain based products: A guide for educators and consumers. *Mind, Brain, and Education*, *4*(1), 1-7. doi: 10.1111/j.1751-228X.2009.01077.x

Takashima, A., Petersson, K. M., Rutters, F., Tendolkar, I, Jensen, O., Zwarts, M. J., McNaughton, B. L., & Fernandez, G. (2006). Declarative memory consolidation in humans: a prospective functional magnetic resonance imaging study. *Proceedings of the National Academy of Sciences of the United States of America*, *103*(3), 756-761. doi: 10.1073/pnas.0507774103

Weisberg, D. S., Keil, F. C., Goodstein, J., Rawson, E., & Gray, J. R. (2008). The seductive allure of neuroscience explanations. *Journal of Cognitive Neuroscience*, *20*(3), 470-477.

Wilson, S. M. & Berne, J. (1999). Teacher learning and the acquisition of professional knowledge: An examination of research on contemporary professional development. *Review of Research in Education*, *24*(1), 173-209.

Appendices

Appendix A: Observation Protocol for Large Group Session

Category	Conceptual Definition	Operational Definitions/Items
Content Integration (CI)	Content integration is an expression where the student takes two seemingly disparate ideas and connects them together based on underlying principles of similarity.	• Defined their understanding of NOS using neuroscience • Described their understanding of NOS using neuroscience • Evaluated neuroscience research based on their understanding of NOS • Compared/contrasted the reliability of neuroscientific findings using NOS as a framework
Discussion Quality (DQ)	Discussion quality refers to the distinctive characteristics of the verbal interactions between students. Discussion quality is categorized as factual, conceptual, analytical, or evaluative, according to Bloom's taxonomy.	• Made brief statements about facts related to neuroscience and NOS (F) • Discussed higher than factual ideas about neuroscience and NOS I • Analyzed ideas about neuroscience and NOS by looking at the whole in terms of its constituent parts and their relationships (A) • Made statements about neuroscience and NOS that were related to judgement (E)

Social Interactions (SI)	Social interactions refer to the verbal and non-verbal methods of communication that students use to communicate with one another. In this case, social interactions refer to the actions of students labeled as 'small group' or 'large group', and how these actions are separated or	• Engaged in discussion only with 'small group' (S) members
		  o Catalyst/focus group
		• Engaged in discussion only with 'large group' (L) members
		  o Everyone minus the small group members
		• Both 'small group' and 'large group' members interacted with each other in their discussions – integrated (I)

	integrated within these two groups.	
Ambiance (AM)	Ambiance is the mood, character, tone, or atmosphere of the classroom, and is based on emotional aspects of the students in that classroom.	• Positive and supportive interactions between students (P) ○ Highlighted strong aspects of other students' statements ○ Critically evaluated other students' statements while acknowledging the plausibility of their statements ○ Used the statements of others to build a larger theory about a topic ○ Of good accord • Negative and hostile interactions between students (N) ○ Drew on negative emotions to make their argument ○ Undermined the quality of arguments without reason

	5 min	10 min	15 min
Content Integration Are they integrating neuro and NOS – yes (Y), or no (N)	Y / N	Y / N	Y / N
Discussion Quality Circle all that apply Factual (F), Conceptual (C), Analytical (A), Evaluative (E)	F / C / A / E	F / C / A / E	F / C / A / E

Social Interactions small group only (S), large group only (L), or both integrated (I)	S / L / I	S / L / I	S / L / I
Ambiance Positive and supportive (P), negative and hostile (N)	P / N	P / N	P / N
	20 min	25 min	30 min
Content Integration Are they integrating neuro and NOS – yes (Y), or no (N)	Y / N	Y / N	Y / N
Discussion Quality Circle all that apply Factual (F), Conceptual (C), Analytical (A), Evaluative (E)	F / C / A / E	F / C / A / E	F / C / A / E
Social Interactions small group only (S), large group only (L), or both integrated (I)	S / L / I	S / L / I	S / L / I

Ambiance Positive and supportive (P), negative and hostile (N)	P / N	P / N	P / N
	35 min	40 min	45 min
Content Integration Are they integrating neuro and NOS – yes (Y), or no (N)	Y / N	Y / N	Y / N
Discussion Quality Circle all that apply Factual (F), Conceptual (C), Analytical (A), Evaluative (E)	F / C / A / E	F / C / A / E	F / C / A / E
Social Interactions small group only (S), large group only (L), or both integrated (I)	S / L / I	S / L / I	S / L / I
Ambiance Positive and supportive (P), negative and hostile (N)	P / N	P / N	P / N
	50 min	55 min	60 min

Content Integration Are they integrating neuro and NOS – yes (Y), or no (N)	Y / N	Y / N	Y / N
Discussion Quality Circle all that apply Factual (F), Conceptual (C), Analytical (A), Evaluative (E)	F / C / A / E	F / C / A / E	F / C / A / E
Social Interactions small group only (S), large group only (L), or both integrated (I)	S / L / I	S / L / I	S / L / I
Ambiance Positive and supportive (P), negative and hostile (N)	P / N	P / N	P / N

	65 min	70 min	75 min
Content Integration Are they integrating neuro and NOS – yes (Y), or no (N)	Y / N	Y / N	Y / N

Discussion Quality Circle all that apply Factual (F), Conceptual (C), Analytical (A), Evaluative (E)	F / C / A / E	F / C / A / E	F / C / A / E
Social Interactions small group only (S), large group only (L), or both integrated (I)	S / L / I	S / L / I	S / L / I
Ambiance Positive and supportive (P), negative and hostile (N)	P / N	P / N	P / N
	80 min	85 min	90 min
Content Integration Are they integrating neuro and NOS – yes (Y), or no (N)	Y / N	Y / N	Y / N
Discussion Quality Circle all that apply Factual (F), Conceptual (C), Analytical (A), Evaluative (E)	F / C / A / E	F / C / A / E	F / C / A / E

Social Interactions small group only (S), large group only (L), or both integrated (I)	S / L / I	S / L / I	S / L / I
Ambiance Positive and supportive (P), negative and hostile (N)	P / N	P / N	P / N
	95 min	100 min	
Content Are they integrating neuro and NOS – yes (Y), or no (N)	Y / N	Y / N	
Discussion Quality Circle all that apply Factual (F), Conceptual (C), Analytical (A), Evaluative (E)	F / C / A / E	F / C / A / E	
Social Interactions small group only (S), large group only (L), or both integrated (I)	S / L / I	S / L / I	

Ambiance Positive and supportive (P), negative and hostile (N)	P / N	P / N	

Appendix B: Attitudes and Beliefs about NOS-Neuroscience Connections Survey

Pre-Survey: Attitudes and Beliefs about NOS-Neuroscience Connections

1. Using examples from neuroscience research can be a good context for understanding the nature of science (NOS).

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

2. It may be easier to make connections between NOS and neuroscience if a teacher knows more about the neuroscientific domain.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

3. Neuroscience and NOS are disparate scientific endeavors and bear few obvious connections to one another.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

4. I am interested in the integration of NOS and neuroscience to better understand NOS concepts.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

5. I believe that it is necessary to learn NOS to be an effective science educator.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

6. It is possible to explain NOS concepts using evidence from the neurosciences as scientific examples.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

7. There is a meaningful and logical relationship between neuroscience and NOS.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

8. The many qualities of NOS are an excellent resource that should be used to better understand how scientific knowledge is developed and evolves over time.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

9. I believe that it is valuable to learn the various historical and philosophical aspects of NOS.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

10. Applying NOS principles to a science discipline that we teach is useful for developing a holistic understanding of NOS.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

11. I find learning about NOS to be a rewarding experience.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

12. In my opinion, learning about NOS can enhance my understanding of a science domain.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

Post-Survey: Attitudes and Beliefs about NOS-Neuroscience Connections

1. Using examples from neuroscience research can be a good context for understanding the nature of science (NOS).

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

2. It may be easier to make connections between NOS and neuroscience if a teacher knows more about the neuroscientific domain.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

3. Neuroscience and NOS are disparate scientific endeavors and bear few obvious connections to one another.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

4. I am interested in the integration of NOS and neuroscience to better understand NOS concepts.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

5. I believe that it is necessary to learn NOS to be an effective science educator.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

6. It is possible to explain NOS concepts using evidence from the neurosciences as scientific examples.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

7. There is a meaningful and logical relationship between neuroscience and NOS.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

8. The many qualities of NOS are an excellent resource that should be used to better understand how scientific knowledge is developed and evolves over time.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

9. I believe that it is valuable to learn the various historical and philosophical aspects of NOS.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

10. Applying NOS principles to a science discipline that we teach is useful for developing a holistic understanding of NOS.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

11. I find learning about NOS to be a rewarding experience.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree

[1] [2] [3] [4] [5]

12. In my opinion, learning about NOS can enhance my understanding of a science domain.

Strongly disagree Disagree Neutral/Not Sure Agree Strongly agree
[1] [2] [3] [4] [5]

13. I feel more confident in including neuroscience and NOS in my teaching.

Strongly disagree Disagree Neutral/Not Sure Agree Strongly agree
[1] [2] [3] [4] [5]

14. By participating in this part of the course, I found it useful to think about integrating neuroscience ideas with NOS as a way of clarifying the meaning of NOS.

Strongly disagree Disagree Neutral/Not Sure Agree Strongly agree
[1] [2] [3] [4] [5]

15. I believe that students would be positively attracted to learning science when neuroscience and NOS are integrated, based on what I learned so far.

Strongly disagree Disagree Neutral/Not Sure Agree Strongly agree
[1] [2] [3] [4] [5]

16. Many features of NOS can be identified and exemplified in neuroscience.

Strongly disagree Disagree Neutral/Not Sure Agree Strongly agree
[1] [2] [3] [4] [5]

17. I would recommend that someone attempting to learn NOS could use some aspects of neuroscience to increase their understandings.

Strongly disagree Disagree Neutral/Not Sure Agree Strongly agree
[1] [2] [3] [4] [5]

18. As a result of this course, neuroscience has helped me to see NOS from a different perspective.

Strongly disagree Disagree Neutral/Not Sure Agree Strongly agree
[1] [2] [3] [4] [5]

Appendix C: Mid-Intervention Reflection Prompts

Mid-Intervention Reflection Prompts

1. Do the ideas in the readings we have had so far for this class fit our discussions of the nature of science (NOS)? How have your ideas about NOS changed over the course of this intervention? *In your discussion, try to focus on the elements of tentativeness, creativity, observation vs. inference, subjectivity, and relationships of theory and law.*

2. In what ways have your experiences in this intervention *(the neuroscience lectures, the lesson study, the NOS activities, and the focus group if you are in one)* impacted the attitudes that you may carry towards using neuroscience and/or NOS to inform science teaching and learning?

Appendix D: Post-Intervention Reflection Prompts

Post Intervention Reflection Prompts

Use the space below to reflect on the nature of science as you have learned it thus far in the course. How have your thoughts changed? How have they stayed the same? Do you have questions or concerns about those progressions? Do you feel as though you have egressed in any way?

I used to think ...	**Now I think ...**

Appendix E: Catalytic Group Session Discussion Facilitation Guide

Note: These sessions are discussion based, meaning that by the end of the session, you will have broadly discussed the two questions below. Please indicate your discussion points for each question on the sheet, including other questions that arose during the discussion. On the final page, you will create a collaborative set of final points and discussion questions that you would like to share with the entire class during the next class meeting. You will be instructed to spend about 25 minutes on questions 1 and 2, respectively, and 10 minutes on question 3.

1. Are there any connections that can be made between the neuroscience topic that was discussed in the class meeting (Session 1: Memory, or Session 2: Attention) with the nature of science as we have learned thus far in the course?

2. How can ideas of the nature of science gained in prior sessions of the course can be integrated with neuroscience in education as curriculum topics (i.e. the lesson plans that we used for lesson study and the lesson plans that you wrote prior to the first neuroscience class session)?

3. What were the main points of your focus-group discussion (questions 1 and 2) that you would like to bring back to the next class meeting? What questions do you have that you would like to propose to the class during the next class meeting?

Appendix F: Catalytic Group Reflection Prompts

Catalytic Group Reflection Prompts

---

1. How have your experiences in the focus group contributed to your attitudes about connecting neuroscience and NOS and using those domains of knowledge in science teaching and learning?

2. How do your experiences in the normal class setting (with other students of the course) adhere to or stray from the conversations you have had in the focus groups? Is there space in the large group for you to continue the conversations that you have had in the focus group, or are these experiences largely separate from one another?

Chapter 5

RESULTS

Case Study of Three Students in a Neuroscience-Based Teacher Education Course to Develop Conceptions of the Nature of Science

Abstract

This is a study of three students in a research study who engaged in a four-week course on the integration of neuroscience and the nature of science. The study was designed for science teachers who were enrolled at a large, urban, northeastern university, where neuroscience was provided as a method for participants to understand the complex nature of science (NOS). Using a conceptual framework of conceptual change, three cases were identified that provided insight into participant interactions during the four-week course. Based on the results of this study, three main findings are reported: (1) the degree of appropriateness of neuroscience for contextualized NOS instruction may be varied based on students' perceived intelligibility of neuroscience, (2) when context-specific NOS instruction is utilized, it is imperative that students connect the specific context used for instruction to their own scientific knowledge and experiences, and (3) when students are learning the NOS, those learning opportunities must have perceived value and relevance to the professional development of students. The findings from this study provide evidence of the usefulness of integrating neuroscience and the NOS in the quest to better understand the nature of the scientific discipline. In this study, neuroscience was particularly useful because of its character as a 'contemporary science story', where the tenets of NOS are explicit and easy to see. Areas of future research are also explored, with suggestions on the use of neuroscience to teach the complex NOS.

Introduction

A well-established understanding of the nature of science (NOS) is considered necessary for developing both scientific literacy and effective science teaching practices. As such, the NOS has been included in science education reform documents to enhance teachers' and students' understandings of modern practices of science (National Research Council [NRC] 1996, 2011; NGSS Lead States, 2013). Science education research shows that an explicit and reflective approach to teaching NOS is an effective method for teaching the NOS (Abd-El-Khalick, 2001; Akerson, Abd-El-Khalick, & Lederman, 2000; Duschl & Grandy, 2013; Lederman, 2007; Schwartz & Crawford, 2004). However, this explicit, reflective method, emphasizing the fundamental epistemological and historical roots, is not necessarily successful; many teachers still struggle to translate their understandings of the NOS into classroom practice. Therefore, an approach that utilizes a broader perspective may provide a more professionally relevant context for science teachers. Among other potentially useful contexts, recent research in teacher education has shown that neuroscience has a positive effect on classroom practice (Bernardon, 2013; Dubinsky, 2010; Dubinsky, Roehrig, & Varma, 2013; Roehrig, Michlin, Schmitt, MacNabb, & Dubinsky, 2012). Moreover, there is evidence that teachers are interested in learning the intricacies of the brain as it applies to learning (Roehrig *et al.*, 2012). Integrating neuroscience with the NOS may provide a particularly useful context for understanding the complex NOS because neuroscience is typically classified as a 'contemporary science story'. These contemporary science stories explicitly display the tenets of NOS that are important for teachers and students to understand. These stories have had a positive impact on contextualized NOS instruction (Clough, 2006). This study investigates an alternative approach to teacher education about the NOS, whereby teachers are engaged in learning the NOS while situated within the context of science curricular examples of how neuroscience can inform pedagogy. Two research questions were addressed:

1. How do students in a 4-week neuroscience-based teacher education course change their understandings of the NOS as a result of this teacher education course?
2. How do students change their perceptions of the NOS, neuroscience, and their integration as a result of this teacher education course?

A case-study approach was used to document three participants' conceptual development progressively during a four-week professional development course on the NOS and neuroscience.

Literature Review

The nature of science (NOS) is concerned with how scientific knowledge has evolved over time, including the cultural and social impacts that have altered its merits (Abd-El-Khalick, Bell, & Lederman, 1998; Lederman, 2007). The most commonly accounted-for features of NOS utilized in science education are the 'Lederman 7', where it is necessary to understand the tentativeness and subjectivity of science in addition to cultural and social influences on this body of knowledge (Duschl & Grandy, 2013; Lederman, 1999; Lederman, 2007). Research on improving teachers' understandings of the NOS using an explicit-reflective approach (Abd-El-Khalick, 2001; Abd-El-Khalick & Lederman, 2000; Lederman, 2007; Schwartz & Crawford, 2004) has shown that such an approach increased teacher understanding of the NOS, but not a sustained application in classroom practice (Akerson, Morrison, & McDuffie, 2006; Lederman, 1999).

As neuroscience makes its way into the field of education and society writ large, it is important that teachers learn about neuroscience in a way that improves their critical reading of the research (Serpati & Loughan, 2007; Sylvan & Christodoulou, 2010; Willingham, 2006). Thus, there are implications of learning neuroscience in relation to teachers' scientific literacy (McCabe & Castel, 2008; Weisberg, Keil, Goodstein, Rawson, & Gray, 2008). Additionally, recent research on the effectiveness of teaching neuroscience to teachers stemmed from a set of summer workshops called BrainU, where in-service teachers engaged in inquiry-based learning experiences on neuroscience that have implications for pedagogy. Teachers who have participated in BrainU developed a better conception of the understanding of scientific processes and the nature of experimentation, and thus the NOS (Roehrig *et al.*, 2012). Based on an initial survey of the neuroscientific themes of the BrainU workshop materials, the researcher engaged in a professional consultation with a neuroscience education expert (A. Holland, personal communication, June 9, 2017). This consultation provided three main areas of neuroscience which have the most explicit and transferrable connections to classroom practice: memory, attention, and emotion regulation. Based on the results of this consultation, a survey of neuroscience research relevant to education was conducted that verified the selection of these three neuroscience themes (Corbetta, Kincade, Ollinger, McAvoy, & Shulman, 2000; Gilboa, Winocur, Grady, Hevenor, & Moscovitch, 2004; Graziano, P. A., Reavis, R. D., Keane, S. P., & Calkins, 2007; Hopfinger Buonocore, & Mangun, 2000; Ohman, Flykt, & Esteves, 2001; Takashima *et al.*, 2006).

A reform-approach to professional development (PD) was utilized in this study to allow for a situated experience, whereby relevant professional practices are emphasized, thus improving the potential for teachers to apply the content. To have an effective, reform-oriented PD, teachers must have the opportunity to critically reflect on the content, be given time to apply the topics to curricular strategies and recognize the coherence of the content of the PD with their own pedagogy (Penuel, Fishman, Yamaguchi, & Gallagher, 2007). Additionally, the PD must establish a community of practice, whereby teachers work collaboratively with one another, gaining professional knowledge within the context of a shared community (Akerson, Cullen, & Hanson, 2009; Grossman, Wineburg, & Woolworth, 2001; Palinscar, Magnusson, Marano, & Brown, 1998; Wenger, 1998). Thus, the context for teachers' work is critically important for developing their professionally relevant ideas. The strategy of fostering communities of practice is intimately related to situated learning, where learners in a professional community will move from peripheral to a more central role as they construct knowledge (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991).

The conceptual change model (CCM) was the theoretical framework that guided the analysis of the evidence collected in this study. The conceptual change model is based on the theory of conceptual change, which explains how the central organizing concepts that guide one's knowledge has the ability to change. This change is based on a series of steps that one must undergo to successfully change their previous conception of a particular entity to a new conception. The first step of the conceptual change process is that the learner is presented with new evidence about an entity that runs counter to their current conception of said entity (Hewson & Hewson, 1984; Pintrich, Marx, & Boyle, 1993). The next three steps describe the way in which the learner embraces this new and adopts this evidence into their organizing concepts (Hewson & Hewson, 1984; Pintrich *et al.*, 1993). The first of the three steps is intelligibility, or the idea that a learner can understand what the evidence is trying to say about the entity. The second of the three steps describes the application of the new evidence to specific scenarios within which the entity exists; this is termed plausibility. The final of the three steps is fruitfulness, which describes the level of conviction with which this new evidence can describe the scenario that includes the entity. The successful embracement of these three steps indicates that a learner has changed their conception about the entity under question. The CCM model provided a lens through which the researcher could better understand how participants changed their own conceptions of the NOS and the integration of neuroscience and the NOS as a result of the four-week course.

Methodology

Field Setting and Participants

Seventeen students enrolled in a graduate level teacher education course were solicited to participate in this experimental professional development course at a large, northeastern university in the United States. The IRB Board of Approval granted approval of the research study under an exempt status. Of those 17 students, three were purposefully selected for a case study analysis. The three participants chosen for the case study were purposefully selected based on their performance in the class and the overall research data collected, especially because they served as exemplars of a range of responses reflective of the larger group. All case study participants' names are pseudonyms. The details of their demographics and background will be presented at the beginning of the presentation of their cases in the Results section.

Procedures

A mixed-methods case-study approach was selected to illustrate the multiple, varied perspectives and educational progressions of participants who participated in this neuroscience-based, NOS course. The merits of a case study include opportunity to more fully and extensively document how individual participants experience a unique situation, such as this teacher education course (Trainor & Graue, 2013). These experiences are often documented through multiple sources of data (Creswell, 2012; Trainor & Graue, 2013). Additionally, a case study proves valuable in this research study, as it documents more holistically the experiences of the students in the teacher education course under investigation (Creswell, 2012). This extensive documentation occurs through an analysis of both quantitative and non-quantitative evidence of actions, events and dynamics of human interaction within a specific research context. Additionally, a mixed-methods approach to case study synthesizes a more holistic interpretation of the participants' experiences and developmental progress during the course. In this study, the qualitative evidence was used to provide a more elaborate description of the ways (measured quantitatively) in which their attitudes toward the integration of the NOS and neuroscience change over the four-week course.

Professional course structure. A four-week professional development course was selected for the bounded system within which the case study was conducted. The 17 participants in the course engaged in four large-group sessions on a variety of topics that occurred weekly over the duration of the course. Figure 1 indicates the content of the four large group sessions. In the first three meetings of the large-group sessions (top row of Fig. 1), participants were presented three mini-lectures on different neuroscience topics: (1) Memory, (2) Attention, and (3) Emotion regulation. After each neuroscience topic presentation, participants transitioned into a lesson plan analysis, where they analyzed prepared lesson plans (distributed to the class) for aspects of neuroscience, relevant to the neuroscience topic of the day, and the NOS. Lastly, in each session they held broader discussions about selected topics of the NOS. In the fourth and final large group session, participants summarized the neuroscience content that they had learned over the course of the four weeks, including neuroscience connections to the NOS, and engaged in a lesson planning activity related to the Next Generation Science Standards. In addition to the large group sessions, two groups of three students each (a total of six participants) met in small groups outside of class to discuss the NOS and neuroscience (bottom row of Fig. 1). Their role was to serve as a discussion stimulator (catalyst) in the very next large group meeting. Figure 1 illustrates how these catalytic groups alternated between Sessions 1 and 2, and Sessions 2 and 3, of the large group setting (oblique arrows). The purpose of these catalytic group meetings was to think creatively and be prepared to lead the neuroscience and the NOS discussions in the larger group setting.

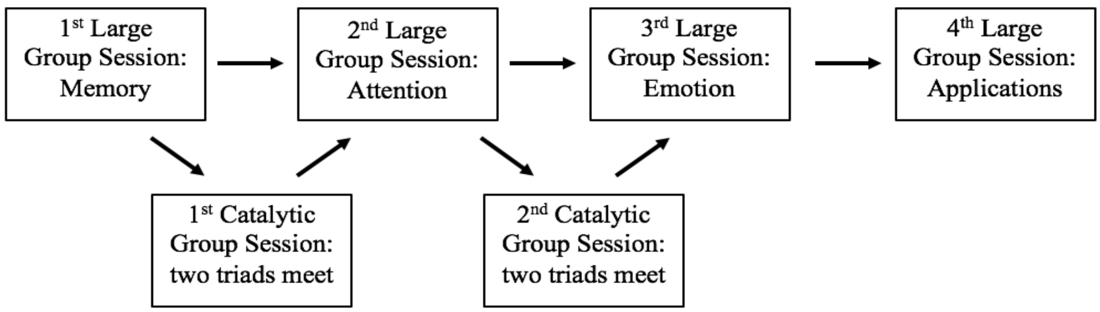

Figure 1: Design of the PD Intervention. Design of the alternating large group and catalytic group sessions to show the integration of catalytic group themes into the larger group lesson setting.

Sources of evidence in the study. There are four sources of evidence used to address the research questions. The first source was a Likert survey developed by the author of this study: Attitudes and Beliefs about the Integration of NOS and Neuroscience Questionnaire (AB NOS) [*Appendix A*]. The second source of evidence was based on a qualitative analysis of the narrative in mid-intervention reflection reports written by the participants during their own time, outside of class [*Appendix B*]. The purpose of the reflection report was to allow participants to engage in critical reflection based on the NOS topics discussed in the large-group sessions. Reflections are an important aspect of an effective, explicit-reflective approach to learning the NOS. The reflection report was completed in the middle of the course (after Session 2). The third source of evidence was a catalytic group reflection report, which was written by the participants during their own time after the course [*Appendix C*]. The purpose of this report was to measure changes in participants' thoughts as they were granted opportunities to reflect at multiple points in their progression during the PD sessions. The fourth and final source used in this study were transcriptions of audio recordings captured during the catalytic group lesson setting. These audio recordings were transcribed by the researcher, where participants' voices were labeled using pseudonyms. Open coding, using NVivo Software, was the source of evidence to analyze the participants' narrative in the written reports. Content analysis was then used in further analyses to identify larger patterns across the different sources of the qualitative evidence for each case.

Role of the researcher. The researcher acted as a full participant in the large group setting, leading participants in discussion-based activities on the integration of neuroscience and NOS. In the catalytic group setting, the researcher was a participant observer, facilitating the discussions on the integration of neuroscience and the NOS as necessary. It is important to note that the role of facilitator in the catalytic group setting was not to promote a particular outcome of the discussion but to sustain interactions among the group members as they discussed the integration of neuroscience and the NOS.

Results

The three cases are presented focusing on the dynamics of each individual's conceptual development during the four-week experience, followed by a section on cross-case perspectives that integrate the interpretations among the three cases presented. The two research questions in this study are addressed through the lens of an analysis of three case studies.

Case 1: Liam

Liam provides the first approach chronicled in the three case studies, because it particularly emphasizes some of the complexities and gains that this innovative course engendered. Given Liam's extensive background in scientific practice, it was hard for him to synthesize the philosophical and subjective tenets of the NOS with the form of scientific knowledge and practice that he experienced. He developed a meaningful conception of the NOS and neuroscience, particularly given his background as a biologist. However, it was separated from the scientific knowledge and practices that he possessed in addition to those that characterized neuroscience.

Demographics. Liam is a graduate, science education doctoral student who possesses a master's degree in biology and has a significant background publishing research in the field of biology. Liam identifies as an African/African-American/Black Male and has enrolled in the doctoral program to work closely with the instructor of the course to look critically at urban science education. In the research objective, Liam participated both as a member of the large group lesson setting and as a catalytic group participant.

Survey Evidence. Liam's results for the Attitudes and Beliefs (AB NOS) Survey are presented in Table 1.

Table 1

Attitudes and Beliefs (AB NOS) Survey Pre- and Post-Lesson Responses, Case 1

Item	Pre	Post
1. Using examples from neuroscience research can be a good context for understanding the nature of science (NOS).	SA	N
2. It may be easier to make connections between NOS and neuroscience if a teacher knows more about the neuroscientific domain.	N	A
3. Neuroscience and NOS are disparate scientific endeavors and bear few obvious connections to one another.	D	D
4. I am interested in the integration of NOS and neuroscience to better understand NOS concepts.	A	N
5. I believe that it is necessary to learn NOS to be an effective science educator.	SA	SA

(continued)

Table 1 (continued)

Attitudes and Beliefs (AB NOS) Survey Pre- and Post-Lesson Responses for Case 1

Item	Pre	Post
6. It is possible to explain NOS concepts using evidence from the neurosciences as scientific examples.	A	A
7. There is a meaningful and logical relationship between neuroscience and NOS.	A	N
8. The many qualities of NOS are an excellent resource that should be used to better understand how scientific knowledge is developed and evolves over time.	A	SA
9. I believe that it is valuable to learn the various historical and philosophical aspects of NOS.	A	SA
10. Applying NOS principles to a science discipline that we teach is useful for developing a holistic understanding of NOS.	A	SA
11. I find learning about NOS to be a rewarding experience.	SA	SA
12. In my opinion, learning about NOS can enhance my understanding of a science domain.	SA	SA
13. I feel more confident in including neuroscience and NOS in my teaching.	--	A
14. By participating in this part of the course, I found it useful to think about integrating neuroscience ideas with NOS as a way of clarifying the meaning of NOS.	--	D
15. I believe that students would be positively attracted to learning science when neuroscience and NOS are integrated, based on what I learned so far.	--	A
16. Many features of NOS can be identified and exemplified in neuroscience.	--	A
17. I would recommend that someone attempting to learn NOS could use some aspects of neuroscience to increase their understandings.	--	A
18. As a result of this course, neuroscience has helped me to see NOS from a different perspective.	--	A

Note: D = strongly disagree or disagree, N = neutral, A = strongly agree or agree. First column represents the Likert-items, column 2 represents responses on the pre-test, column 3 represents responses on the post-test. The dashes marked in the pre-survey column for Items 13-18 of the indicate that no responses were collected, because the items were only appropriate to assess after the end of the course.

In the AB NOS pre-course survey, Liam indicated that he was interested in learning about the NOS in that it was both necessary to be an effective science educator and that the NOS can enhance his understanding of the science domain; these indications were represented in a positive response (agree (A) or strongly agree (SA)) to Items 4, 5,8, 9, 10, 11, and 12. Additionally, Liam initially indicated that he had a positive outlook on connecting neuroscience and the NOS, indicating that the two domains are not disparate and that it may be possible or even beneficial to connect the two domains in an effort to better understand the NOS. These indications were represented in positive responses to Items 1, 6, and 7 and a negative response (disagree (D)) to Item 3. Lastly, Liam was unsure of the necessity of being familiar with neuroscience in order to connect it to the NOS, as indicated by a neutral response (N) to Item 2. It was of interest that, given Liam's significant background in science and scientific research, he was unsure of neuroscience content familiarity as a grounding to connect neuroscience to the NOS. He otherwise responded in a cohesive and positive way to connecting neuroscience and the NOS as a way to better his understanding of the NOS.

In the AB NOS post-course survey, Liam shifted his thinking to a neutral perspective on his interest in and the usefulness of connecting neuroscience and the NOS to better understand the NOS, as indicated by his responses to Items 1 and 4. Additionally, Liam shifted his perspective on the importance of the NOS in teaching and understanding science to strongly agree (SA) with Items 5, 9, 10, 11, and 12. He maintained his agreement that neuroscience and the NOS are not separate endeavors and that it is possible to explain the NOS using neuroscience, as indicated by a positive response to Items 2 and 6. However, he shifted his perspective on the meaningful relationship between neuroscience and the NOS to a neutral response, as indicated in Item 7. Liam did not believe that his experience in the course helped to clarify his understanding of the NOS, as indicated in Item 14. He did, however, feel more confident in his ability to integrate neuroscience and the NOS in his teaching and would recommend that someone attempting to learn the NOS use examples from neuroscience, as indicated by a positive response to Items 13 and 17. He additionally agreed that using neuroscience helped him to see the NOS from a different perspective, as indicated in Item 18. It is interesting to note his incongruous responses to Items 13-18. Liam felt positively that neuroscience helped him to see the NOS from a different perspective and that he would recommend this approach for others, but he did not believe that neuroscience was a good tool to clarify his understanding of the NOS.

Catalytic Group Experiences. Liam's experiences in the catalytic group discussion further highlight the struggles he faced in integrating neuroscience, or science in general, into his developing understanding of the NOS. Initially, he stated that he was "familiar with neuroscience and that part was easy, but [he was] still trying to figure out how to apply it to the readings from class". He made mention that he was most likely "overthinking it, trying to draw some deep correlation when [he] could really just talk". As his conversation progressed, Liam was able to discuss how biology has not really evolved in the last 50 years as opposed to neuroscience, which has been evolving more recently. He stated that "it's time to incorporate more women and people of color to attempt to diversify [biology] because if you have the same people discussing it then you will always have the same facts". He went on to think about science in society on a larger scale, calling into question, "how do we know that we know something and how can we trust the knowledge we are given or the data we receive?". Generally speaking, Liam made claims about where scientific knowledge came from and what factors influence its merit. He did not, however, correlate these claims with his own scientific knowledge and experiences.

Liam made some interesting arguments about how he believes that science maintains an 'elite' status in society, where typical laypeople do not have access to science for two reasons.

First, he discussed the role that the government might play in what science knowledge is accessible to the public. He described how there may be cures for cancer or male baldness, but that the capitalist American society prohibits that sort of science information from being displayed to the world. In other words, Liam argued that the government plays a role in what scientific information gets released to the public, and that this control navigates the way science research progresses and what scientists choose to focus on in their own studies. Additionally, Liam argued that the role of language in science also contributes to its 'elite' status in society. He described how science is an entirely separate language with domain-specific words. Liam questioned "how far [you] should explain the language... even in accounting, do you teach them all the words in accounting, and then in biology, and geography? At what point does it stop and at what point should it stop?" As a result of the catalytic group experiences, Liam could describe how society and culture played a role in what science people know about and have access to, in addition to discussing the need for increased presence of people of color in science, who, in his opinion, can offer multiple perspectives on scientific data which may push the field forward.

Liam's discussions in the catalytic group revealed one interesting finding on his perspectives of what science actually includes, and this finding seemed to run counter to his understanding of sociocultural influences on science. In reflecting on his own experiences as a published biology researcher, he felt as though certain types of science "do not have to do experiments to prove what they are saying, they can just publish [their theories]". Liam went on to describe the importance of experiments in "valuable" scientific research, but he maintained a narrow perspective of what an experiment looks like in science. He described science experiments as "say, temperature and seeing the color change and all of that and seeing pressure and all of that. He then went on to describe his experience hearing about "non-traditional" experiments, where he described that, “when [he heard ‘oh yeah, these meta-physicists create these theories and try to back them up somehow’, [he] was like yea that’s not right”. It was clear from Liam’s catalytic group experiences that he had difficulty connecting his conceptions of the NOS to his actual science experiences. As a published biology researcher, Liam maintained a traditional view of scientific methodology, in that experiments are run in a laboratory, and must have multiple, measurable variables. Thus, Liam’s understanding of the NOS from a sociocultural perspective remained separate from his views of how science actually operates on an experimental, day-to-day level.

Reflection Reports. Liam indicated that he has always kept neuroscience in mind as he has worked and published in the field of biochemistry research. He stated that “NOS is nice to comprehend and [he] does see [it in] biology”, but that it was “very natural to see it.” Liam did not use any examples to describe the ways in which the NOS was easy to see in biology. He explained that he could see the NOS in biology due to studying evolution and seeing how theories changed over time, especially in the early years of biology research when technology was still advancing. He explained in his post-course reflection that “everything is intertwined and is influenced by something else” but did not apply this knowledge to neuroscience or biology in general.

Liam responded positively when asked about his experiences in the catalytic group. He described how he had more of a voice in the focus group, but he also got to hear the perspectives of everyone in the catalytic group setting. Liam claimed that being able to hear the multiple perspectives of his group members allowed him to reflect on his own viewpoints. Liam felt as though the conversations in the catalytic group were more grounded in the viewpoints of the participants, and that the participants had the ability to sway the conversation where they felt it should go. As a result, Liam felt that he learned more from the catalytic group setting because he had more of an opportunity to share his own beliefs with other students and subsequently reflect on them.

Overview. There are a few very important ambiguities that Liam's case presents in this course. At first, Liam had a very positive and open mind towards the meaningful relationship that could be made between neuroscience and the NOS, indicating that it would be helpful in developing a better understanding of the NOS. After the course, he no longer believed that the relationship between neuroscience and NOS was neither meaningful nor helpful in understanding the NOS on a more nuanced level. Yet, he suggested that this course might be suitable for other teachers who are curious about developing their understandings of the NOS. In the reflection reports, Liam presents an alternative case, where he states that in his previous science field experience, he was consistently keeping the NOS in mind. He could not, however, explicitly describe how the NOS was connected to his own experiences in the field of biology. In his reflection reports, He explained how the NOS was present in biology as theories changed over time, but in his catalytic group experiences, he explicitly stated that the field of biology has not changed in the past 50 years. Despite Liam's ability to recognize neuroscience as a contemporary science story that was still evolving, he did not see the fruitfulness of using neuroscience to study the abstract tenets of the NOS.

In general, Liam illustrated a belief in the subjectivity and sociocultural aspects of science by discussing how many things are influenced by something else. In his catalytic group experiences, Liam described the way in which science holds an 'elite' status in society. He claimed that the government plays a role in what scientific research society can have access to, in addition to describing how the role of scientific language affects one's ability to digest scientific research. In this sense, Liam described how the shifting values and norms within science are influenced by society and mainstream cultures. As such, Liam exhibited a constructivist perspective throughout this course.

However, Liam did not apply his ideas about subjectivity or sociocultural aspects of the NOS to neuroscience or biology in general. More specifically, he did not discuss how neuroscience or biology knowledge is affected by societal or cultural influences on science and/or the scientists that affect what knowledge is produced. Rather, he described that scientists may find interesting results in their scientific research, but that the government ultimately decides if those things will become public knowledge. He also described how "real science" uses a traditional form of experiments, where these experiments can objectively prove a theory. He argued that this type of experiment and proof runs counter to what one would see in conceptual science or social science, where Liam believed that people could publish whatever they want without using scientific experiments. Additionally, Liam's case indicated that he did not interrogate his own understandings of science, or of biology. He did not call into question the scientific knowledge that he held, but he stated that this is an important aspect of understanding the NOS. Liam struggled to apply his NOS understandings to his own science knowledge and experiences. Despite Liam's well-developed views of the sociocultural influences on science, he maintained a traditional view of what counts as science and what holds merit in scientific research, leaving his own scientific understandings untouched by his views of the NOS. He maintained a separate understanding of neuroscience, or biology, and the NOS.

Case 2: Jackson

In Case 2, Jackson presents an interesting approach to utilizing neuroscience to understand the NOS. Jackson used the context of the catalytic group discussions to interrogate the NOS at a broader level. In other words, Jackson specifically credits the smaller discussion setting as presented in the catalytic groups as a purposeful space to critically analyzing scientific knowledge and practices, in addition to considering the frame of mind that scientists possess as they practice in the domain of science. The catalytic group discussions allowed Jackson to develop a critical NOS lens, where he could apply this lens to both neuroscience and his own scientific domain expertise. However, as an Earth scientist, he also confronted some challenges merging the neuroscientific aspects with his goal of teaching Earth sciences.

Demographics. Jackson is a master's student enrolled in the science education certification program. Jackson identifies as a Caucasian/White male with a bachelor's degree in geophysical science. Jackson's goal is to teach in public science classrooms. In the study, Jackson acted as a large group session participant and a catalytic group member.

Survey Evidence. Jackson's results for the Attitudes and Beliefs (AB NOS) Survey are presented in Table 2.

In the pre-course survey (Table 2), Jackson's positive responses (A or SA) to Items 5, 8, 9, 10, and 12 indicated that he believes it is important to learn the NOS to better understand science and to be a better science educator. However, his neutral response (N) to Items 3, 6, and 7 indicate that he was unsure of the potential connections that could be made between neuroscience and the NOS. He was, interested in learning about how neuroscience and NOS could be connected, as indicated by a positive response (A) to Item 4.

Table 2 (continued)

Attitudes and Beliefs (AB NOS) Survey Pre- and Post-Lesson Responses, Case 2

Item	Pre	Post
1. Using examples from neuroscience research can be a good context for understanding the nature of science (NOS).	A	A
2. It may be easier to make connections between NOS and neuroscience if a teacher knows more about the neuroscientific domain.	SA	SA
3. Neuroscience and NOS are disparate scientific endeavors and bear few obvious connections to one another.	N	D
4. I am interested in the integration of NOS and neuroscience to better understand NOS concepts.	A	N
5. I believe that it is necessary to learn NOS to be an effective science educator.	SA	SA
6. It is possible to explain NOS concepts using evidence from the neurosciences as scientific examples.	N	A
7. There is a meaningful and logical relationship between neuroscience and NOS.	N	A
8. The many qualities of NOS are an excellent resource that should be used to better understand how scientific knowledge is developed and evolves over time.	SA	SA
9. I believe that it is valuable to learn the various historical and philosophical aspects of NOS.	SA	SA
10. Applying NOS principles to a science discipline that we teach is useful for developing a holistic understanding of NOS.	A	SA
11. I find learning about NOS to be a rewarding experience.	SA	SA
12. In my opinion, learning about NOS can enhance my understanding of a science domain.	SA	SA
13. I feel more confident in including neuroscience and NOS in my teaching.	-	N
14. By participating in this part of the course, I found it useful to think about integrating neuroscience ideas with NOS as a way of clarifying the meaning of NOS.	-	N
15. I believe that students would be positively attracted to learning science when neuroscience and NOS are integrated, based on what I learned so far.	-	D
16. Many features of NOS can be identified and exemplified in neuroscience.	-	A

(continued)

Table 2 (continued)

Attitudes and Beliefs (AB NOS) Survey Pre- and Post-Lesson Responses, Case 2

Item	Pre	Post
17. I would recommend that someone attempting to learn NOS could use some aspects of neuroscience to increase their understandings.	-	A
18. As a result of this course, neuroscience has helped me to see NOS from a different perspective.	-	A

Note: D = strongly disagree or disagree, N = neutral, A = strongly agree or agree. First column represents the Likert-items, column 2 represents responses on the pre-test, column 3 represents responses on the post-test. The dashes marked in the pre-survey column for Items 13-18 of the indicate that no responses were collected, because the items were only appropriate to assess after the end of the course.

In the post-course survey (Table 2), his responses to the importance of the NOS in understanding the science domain and being a better science educator did not change, as indicated by the positive responses to Items 5, 8, 9, 10, 12, and 18. Moreover, Jackson positively shifted his perspectives on the connections between neuroscience and NOS, where he indicated a negative response (D) to Item 3 and a positive response (A) to Items 6, 7, 16, and 17. However, he lost some interest in learning about neuroscience and the NOS, indicated by his neutral response (N) to Item 4. Lastly, Jackson indicated in Items 13 and 14 that he did not necessarily feel more confident in using neuroscience and the NOS in his teaching or that the course helped to clarify the meaning of the NOS, as indicated by a neutral response to Items 13 and 14, and a negative response (D) to Item 15.

Catalytic Group Experiences. Jackson's discussions in the catalytic group setting allowed him to investigate the NOS on a deeper level. He highlights the multiple, varied ways in which neuroscience connects to the NOS and to his subject matter expertise (Earth sciences). Jackson used the catalytic group setting to investigate how both neuroscience and the NOS are connected to one another, and how they have the potential to inform pedagogy in both a positive and negative way. Jackson also investigated the ways in which scientists in different 'sub-domains' interact with one another, calling into question the role of language as a way to separate different science fields.

In the catalytic group discussions, Jackson described how there is a misunderstanding of what the NOS actually is in comparison to how some scientists are trained to understand the NOS. He describes how there is an "inherent amount of fuzziness" when we engage in scientific study, but that "this gets largely ignored by people who [he] think[s] are trained in an understanding of science, but it is really an understanding of physics". As an example, Jackson describes his perspective on neuroscience research stating that,

> My understanding [of neuroscience] is that you can detect areas of activation in the brain and you can correlate that with reported feelings or measurements of feelings. But, I feel like people read this stuff and they're like 'oh this is where your memories are in your brain that make you think this' as opposed to like 'this area of your brain is activated when you do this thing and if you take it out then this thing happens and that's interesting'.

He also describes how the popular understanding of science is actually an understanding of "regularized, formula-based physics", and does not describe other areas of science, such as neuroscience or Earth science. He goes on to explain how other components of science are not included in this popular understanding of science. Those other components include the role of competition in scientific research, writing grant proposals, and relevance to phenomena that society deems important, such as earthquake studies or oil and gas research. He relates much of this perspective to his previous experience working in a mineral physics lab, where every few months, his lab would have to write a new proposal to receive grant money. In this proposal, Jackson notes how they

> would often lie and say that it was related to earthquakes so that we could get money, but it wasn't related to earthquakes. Like, an earthquake doesn't happen because of anything to do with the chemical structure of sulfides, but we needed the money and we needed a practical reason. We all had such disdain for the fact that we had to lie.

Jackson describes how this aspect of science is not necessarily included in the physics-based understanding of science that most people hold, because it does not reflect the large amount of competition that exists to make sure that your scientific research can continue.

Jackson also used the catalytic group experiences to describe how neuroscience actually connected to many of his experiences as an earth scientist. He described how it was a common practice in geology field work to describe one's mindset prior to conducting observations of various geologic landscapes. He related this idea to discussions in the large group session of how emotions affect memory, stating that on days where he felt 'less good', he made fewer claims about the strata he observed. He also described how the journaling of mindset triggered his episodic memory, where he could remember the experience of that day and reflect on the observations he made in his journal. He felt as though this meta-cognitive experience in his Earth science research experience had an important connection to neuroscience and he developed an eloquent explanation for the purpose behind these seemingly random Earth science practices.

Jackson made some interesting connections between neuroscience, the NOS, and classroom learning experiences. He first noted how because context and episodic memory is prioritized in the mind, this was "almost an argument in favor of the 'recipe book' lessons... [because] there is some value to tying [a fact] to some experience, even if it doesn't involve deep cognition". He described, however, that more eloquent views of the NOS often harp on these experiences, in that they are too shallow and too narrow to illustrate what the process of experimentation is actually like for a scientist. He then considered what the goal of including science classrooms actually should be. He wondered if the goal of science classrooms is to "realistically portray the world of science or to portray a more positive and collaborative form of science that may not actually be true to what's happening". He also reflected on his own Earth science lab experiences, where he stated that once you get higher up within a science lab, you are more focused on writing grant proposals and publishing papers. He claimed that much of the time in a science lab is often spent on other tasks outside of actual scientific experimentation.

Last, Jackson described how the role of language in different science fields acts as the mediating factor that keeps these different fields separate from one another. He described how there might be "little bursts of communication between scientists where you come up with things like biochemistry, and a subdomain actually comes out of it". He even applied this idea to neuroscience, where he stated that "things that have the brain as the source of the problem are considered germane to neuroscience, but when it goes slightly further into the sensory organs, it could have a huge effect on the brain that is no longer within the field of neuroscience". He further explained that there might be some "key differences in language when they are discussing the same processes between people who study sensory organs and people who study the brain". Reflecting on this thought, Jackson wondered if there was some sort of "odd pride in the lack of applicability" of science. In other words, Jackson wondered if the different fields of science can maintain their 'elite' status in the domain of science as a whole, so long as these different fields can remain in their separation through the language they use to describe very similar science processes. He also connected this thought to classroom planning, where he stated that,

> “the science we have is ill-suited to the best way to teach it ... the most realistic way to teach energy is as a whole system, but the language that we’ve all learned to talk about energy in for each of these sub-domains is so different that it’s really hard to figure out a cohesive way to explain it to a student, because no one has bothered to think of one. Because you don’t need it to do normal science, you just need your specific language to do your one type of science.

It is clear from Jackson’s catalytic group experiences that he deeply reflected on the larger principles of the NOS, how they are exemplified in both neuroscience and Earth science. In addition, he consistently applied these reflection to implications for his own classroom practice, critically analyzing the version of the NOS that students should be most aware of in their pursuit of science knowledge.

Reflection Reports. After the course, Jackson reported that “NOS is crucial to being scientifically literate [and] can be an excellent ‘hook’ into science learning for those alienated from it.” He highlighted language as an important yet alienating feature of science, where the lack of a common language between neuroscience and other fields “makes obvious the degree to which normal scientific disciplines cling to their specific terminology and methodology.” He further reflected on conceptions of neuroscience related to its alienating language, stating that neuroscience “seems like a standoffish clique prone illogically overreaching statements about the nature of human cognition.”

In his reflections of class discussions, Jackson questioned if the NOS was considered and reflected on by practicing scientists. He called into question the differences in thinking about science from a philosophy perspective versus a practicing scientist perspective. He described that philosophers are correct in identifying the uncertainty and subjectivity of science, but he questioned if scientists recognize these aspects of science, further asking the question "can we really call the nature of a body of knowledge tentative if almost none of the texts that make up that body recognize their own uncertainty? Or, are we just saying that they should?" He continued his reflection by describing how much of the discussion on the NOS ends up as a focus on "harping; harping on scientist, harping on science as an institution, harping on academia specifically, harping on neuroscience specifically". It made him realize how easy, even natural it is to frame NOS in the classroom as the "nature of why science is bad."

Jackson also reflected on how the NOS should be presented to students in classroom and how he wants to frame the NOS in his own classroom. He described how he wanted students to see the NOS as a set of norms for a culture that they can join, and to see that there are flaws in science that are not negative, emphasizing that "tentative ideas are still useful and thoughtful, and if anything, are more brilliant still for their fragility in the face of new thought." He described the impact that the course has had on the ways in which he will teach the NOS to students,

> We model for students the limited fuzziness of scientific claims, but necessarily don't inform them that not all scientists keep those limits in mind when making claims and reaching conclusions. We can walk students through the ways that results are dependent on the methods and instruments used to get them; but that doesn't mean scientists are aware of the fact. The course has made clear for me that we can't present NOS content as an experience in how scientists really operate, because a genuine scientist-like experience would include very little reflection on NOS. We need to explicitly mix scientist-like experiences with reflection on NOS, so that students can learn about science-the-human-endeavor, not just how to uncritically perform the tasks of normal science.

Jackson considered the multiple benefits and issues of how to present the NOS to students in classrooms, where the goal of teaching students the NOS should be to present the philosophies behind science as a social practice in addition to genuine experiences of scientists.

Jackson found that the conversations in the catalytic group setting wandered more than did the discussions in the large group setting. However, Jackson found this to be extremely helpful, because he was given the space to interrogate his own thoughts on integrating the NOS and neuroscience into one cohesive understanding of science. He described that neuroscience provided a “grounding subject” to interrogate the NOS as a whole. He explained that this was different from conversations in the larger group setting, which were much more focused on small aspects of the NOS at a time. Reflection on the NOS from the “big-picture perspective” was something that he found was unique to the catalytic group experiences. He liked using neuroscience to reflect on the NOS from a broader perspective. The catalytic group helped him to form a clearer picture of how he would use the NOS in the classroom and how he would teach the NOS to students.

Overview. Jackson’s perspectives on the integration of neuroscience and the NOS and the utility of the NOS in classrooms changed as a result of this course. Jackson found value in the catalytic group experiences, where he was able to identify both positive and negative aspects of including the NOS in classroom instruction. Additionally, Jackson was able to see the connections between neuroscience and the NOS, Earth sciences and the NOS, and neuroscience and Earth sciences. Jackson found that the course gave him an opportunity to develop a clearer and more holistic understanding of the NOS. However, as a result of this course, Jackson did not see the utility of including neuroscience in an Earth sciences curriculum. Rather, he found that neuroscience provided an informative framework for understanding the NOS, generally, where this more elaborate understanding of the NOS could be carried over to an Earth sciences classroom.

Jackson used neuroscience as a platform to reflect on the NOS from a “big-picture” perspective. He spent much of his time in the catalytic group experiences reflecting on whether an actual “scientist-like experience” includes any meta-cognitive reflection on the NOS. He questioned if we can really describe science through the tenets of the NOS if scientists do not consider these tenets in their own work. As a result, Jackson argued that if the NOS should be taught to students, it should include both the NOS and the way scientists view their own research. Moreover, Jackson thought about how the “fuzziness” of science would play out in classroom instruction. He wondered if the goal of the science classroom was to provide a genuine science research experience, or to provide a positive version of collaborative science. Jackson emphasized that many scientists do not necessarily consider the “fuzziness” of science as this subjectivity is largely ignored by people who are trained in scientific research. Jackson questioned the nature of discussions on the NOS and the limits of those discussions in terms of applications to the minds of scientists and how much students should know about the NOS at a nuanced level. He described how the NOS is valuable for students to know the tentativeness of science, and that that very tentativeness makes science even more beautiful. Additionally, Jackson described how he wanted students to consider the NOS a set of cultural norms that they can elect to adopt if they so choose. Viewing science as a tentative culture had implications for the ways in which he would frame the NOS for students, where Jackson considered showing students the philosophy-side of the NOS describing it as a social practice in addition to the genuine side of how scientists think that they operate. Jackson believed that framing the NOS in this way would allow for a “way in” to science for students, especially those who have felt traditionally alienated from the scientific discipline.

He was able to highlight how neuroscience can inform classroom practice both positively and negatively. He notes that the positive aspect of this connection is that it gives evidence for having students engage in the practices of science. However, he notes that this evidence is in favor of the argument that students should engage in “recipe book labs”, because there is value in attempting to connect scientific knowledge with student experiences. In other words, Jackson saw that at the very least, “recipe book” labs gave students some neuroscientific benefit during the learning process, as opposed to a learning experience that did not include hands-on activities such that the “recipe book lab” can offer students. Additionally, Jackson recognize the issue of communication within the field of neuroscience, and science writ large. Jackson argued that the difference in language between seemingly connected sub-fields of science makes it even harder to teach science to students. He described how the science that we currently have is actually “ill-suited” to the best way to teach it. In other words, Jackson thought that science should be taught through unifying concepts, such as energy, but that because different fields of science do not discuss energy in the same way, it would be impossible to actually teach students in this way.

Jackson made very interesting connections between neuroscience and the NOS in an explicit manner. Jackson found that there were similarities between various Earth sciences practices that he engaged in as a researcher, including a reflection on emotional states when conducting observations of various rock strata. He found that these reflection notes activated what he would classify as his episodic memory, where he could think about the autobiographical experiences of the day for which he was reading his observation notes. He also found that neuroscience provided an exemplar for how language mediates the lack of communication in science. He described how research that looks at the brain as the source of a problem does not necessarily include implications for sensory organs; that would be a different sub-domain of science research. He found this parallel in the Earth sciences, as well as science, generally. He wondered if this was a method to maintain an elite status among varying sub-domains of science.

As indicated by the post-course AB NOS survey (Table 2), Jackson was weary of attempting to connect or apply neuroscience to his own teaching practice as an Earth science educator. Although he valued the situated context of neuroscience as a way to better understand the NOS at a general level, and he suggested that this context may be useful for other educators who wish to better understand the NOS. However, he did not believe that students would find it useful to learn about neuroscience and the NOS in an integrated manner to better understand Earth science. These perspectives are exemplified in his post-course AB NOS survey (Table 2). Jackson found it more useful to use neuroscience as a platform for understanding the NOS, generally, and then carry that general NOS understanding into his classroom practice. This is an interesting finding in that the integration of neuroscience and the NOS may have a different application to classroom pedagogy for different subject matter domains. However, Jackson still largely benefitted from his participation in the course, where neuroscience helped him to see NOS from a different, useful perspective.

Case 3: Using Neuroscience as a Context for Explaining NOS

Sara presents the third case for understanding how one can integrate neuroscience and the NOS. In this case, Sara used her extensive background knowledge of neuroscience to explain the tenets of NOS, in addition to thinking about how those tenets of NOS apply to the field of neuroscience writ large. Additionally, Sara began to meta-cognitively reflect on her own scientific knowledge in addition to how her knowledge of NOS was developing, indicating her ability to integrate the NOS and neuroscience into one cohesive understanding of science.

Demographics. Sara is an interesting case in this research objective because she has the largest content knowledge of neuroscience, garnered through her bachelor's degree in neuroscience. Sara identified as a Caucasian/White female. She is enrolled in a dual-certification program in both science education and deaf education and has a goal of teaching science in a deaf/hard-of-hearing school. Sara participated as both a large group session participant and a catalytic group participant in the same triad as Liam (the first case).

Survey Evidence. Sara's results for the Attitudes and Beliefs (AB NOS) Survey are presented in Table 3. In the pre-course survey (Table 3), Sara agreed that learning the NOS was a valuable experience to help better understand science and was necessary for being an effective science educator, as indicated by a positive response (A/SA) to Items 7, 8, 9, 10, 11, and 12. Additionally, Sara was interested in the connections that could be made between neuroscience and the NOS. She thought that their potential connection was meaningful and served as a good context to understand the NOS, as indicated by a positive response to Items 1, 4, 5, and 6.

Table 3

Attitudes and Beliefs (AB NOS) Survey, Pre- and Post-Lesson Responses, Case 3

Item	Pre	Post
1. Using examples from neuroscience research can be a good context for understanding the nature of science (NOS).	A	SA
2. It may be easier to make connections between NOS and neuroscience if a teacher knows more about the neuroscientific domain.	A	A
3. Neuroscience and NOS are disparate scientific endeavors and bear few obvious connections to one another.	D	D
4. I am interested in the integration of NOS and neuroscience to better understand NOS concepts.	SA	SA

(continued)

Table 3 (continued)

Attitudes and Beliefs (AB NOS) Survey, Pre- and Post-Lesson Responses for Case 3

Item	Pre	Post
5. I believe that it is necessary to learn NOS to be an effective science educator.	SA	SA
6. It is possible to explain NOS concepts using evidence from the neurosciences as scientific examples.	A	SA
7. There is a meaningful and logical relationship between neuroscience and NOS.	A	SA
8. The many qualities of NOS are an excellent resource that should be used to better understand how scientific knowledge is developed and evolves over time.	A	A
9. I believe that it is valuable to learn the various historical and philosophical aspects of NOS.	SA	SA
10. Applying NOS principles to a science discipline that we teach is useful for developing a holistic understanding of NOS.	A	SA
11. I find learning about NOS to be a rewarding experience.	A	SA
12. In my opinion, learning about NOS can enhance my understanding of a science domain.	SA	SA
13. I feel more confident in including neuroscience and NOS in my teaching.	--	SA
14. By participating in this part of the course, I found it useful to think about integrating neuroscience ideas with NOS as a way of clarifying the meaning of NOS.	--	SA
15. I believe that students would be positively attracted to learning science when neuroscience and NOS are integrated, based on what I learned so far.	--	A
16. Many features of NOS can be identified and exemplified in neuroscience.	--	SA
17. I would recommend that someone attempting to learn NOS could use some aspects of neuroscience to increase their understandings.	--	A
18. As a result of this course, neuroscience has helped me to see NOS from a different perspective.	--	A

Note: D = strongly disagree or disagree, N = neutral, A = strongly agree or agree. First column represents the Likert-items, column 2 represents responses on the pre-test, column 3 represents responses on the post-test. The dashes marked in the pre-survey column for Items 13-18 of the indicate that no responses were collected, because the items were only appropriate to assess after the end of the course.

In the post-course survey (Table 3), Sara shifted her perspective to a stronger opinion on the importance of learning the NOS to be a science educator, as indicated in her positive response (SA) Item 5. Sara indicated that applying tenets of the NOS to a scientific context was useful to better understand the NOS as a whole, as indicated by a positive response (SA) to Items 10 and 12. Additionally, Sara shifted her views on the connections between neuroscience and the NOS, indicating in Items 6 and 7 that this connection is meaningful and helps to better understand the NOS. Sara reported that she now feels more comfortable in using neuroscience in her teaching and using neuroscience has helped her to see the NOS from a different perspective, as indicated in Items 13 and 18. Additionally, Sara found it useful to use neuroscience to understand the NOS and she would recommend others to use neuroscience to understand the NOS, as indicated by a positive response to Items 16 and 17.

Catalytic Group Experiences. Sara's time in the catalytic groups allowed for her to reflect on how neuroscience could be integrated into her understanding of the NOS in addition to the role of the science laboratory in understanding the subjective and changing NOS. She also applied her developing understandings of the NOS and neuroscience to her experiences working with deaf/hard-of-hearing students. Sara ultimately found that neuroscience was the perfect context to better understand the NOS because it is so new, and it continues to change and evolve.

Sara's reflections on the potential connections of neuroscience with the NOS began with a personal account of her experiences of neuroscience in society. She recounted how when she tells people that she has a degree in neuroscience, they are highly impressed with her ability to master such a complex scientific discipline. She describes how people "think [neuroscience] is something that is unattainable which it is, and it is not, in the sense that we will never fully master it". In other words, she described how neuroscience is possible to learn, but there will never come a time where we know all the answers about how the brain works. She related this concept to the NOS, where she described that most of science is characterized by the inquiry process, and that allows you to deepen your understanding [of the discipline] without necessarily coming to a solution". Sara found that this concept of the NOS is what was largely missing from society, and most likely describes why people were so impressed by the complex neuroscience discipline.

She further connected the NOS and neuroscience by thinking about how much neuroscience has changed in the last 20 years. She emphasized that because "it is still a newer science, it lends itself in a way to talking about the NOS because [neuroscience] is so changeable and sort of uncertain in a lot of ways". She then made the comment that it was possible that in 20 years neuroscience might not be the best context for better understandings the NOS if there is some form of newer science that is characterized more so by uncertainty and change. She also described how while biology, chemistry, or physics could be helpful for understanding the NOS, the science in those areas (i.e., biology, chemistry, or physics) are less controversial and more readily held by scientists in those fields, whereas in neuroscience things are still largely questionable and debatable. Sara firmly believes that because the subjectivity of science is so transparent in neuroscience, this would be a "good model for teaching the NOS for students, especially for students who may have not seen this stuff before."

Sara also described how science is subjective in the laboratory setting. She described how different types of data have different levels of objectivity, but that any type of data that requires descriptions will be inherently subjective and biased, because it is rooted in the human endeavor. Sara strongly felt as though one of the big purposes of studying the NOS is to understand that "data is not always objective, and we aren't talking about facts." She also stated that so many people feel drawn to science because they believe it is logical and certain, but that it actually gets more philosophical the more you learn about science. She believed that the root of this problem is because we tend to teach students that science is "black and white, x + y = z."

Lastly, Sara reflected a lot on how she would present the NOS in classrooms, especially given her desire to work with deaf/hard-of-hearing students. She discussed how deaf/hard-of-hearing students face more barriers to science because there are not American Sign Language (ASL) hand signs for many science terms. She also discussed how many of her students may not actually be literate in English because they depend on ASL to communicate. She felt it was necessary to present science in a way that all students can interpret and understand, and that multi-modal presentations of science may be very effective for presenting science to her students. In this way, she would be utilizing multiple areas of the brain to create stronger memories for her students. Sara believed that science labs may be a great way to both teach science content to her students and engage them in learning the NOS because they would then be engaged in the subjective nature of the scientific inquiry process.

Reflection Reports. In Sara's reflection reports, she indicates how drastically her ideas have changed over time in regard to the NOS. She previously thought of science as a "black and white, sealed and static 'answer'" about natural phenomena. During the course, she found that,

> [NOS] is a much more philosophical set of ideas and subsequent conversations that contribute to my understanding of what NOS is. And I say specifically 'my understanding' because I am coming to recognize NOS as an almost personal opinion, a very subjective notion, influenced by past experiences, prior knowledge, culture, society, values, and so many other things.

Additionally, Sara described how neuroscience can be a useful context for understanding the complex, philosophical nature of science:

> Since [NOS] is its own entity, which can be difficult to conceptualize and understand, I believe neuroscience concepts can aid in the discussion of NOS practices. Since neuroscience is a more recent field in the world of science, I think it lends itself as a convenient model to explain theories vs. laws, why NOS is important, and its inherent subjectivity... There are often competing views/theories on certain concepts in neuroscience (for instance, in terms of memory and cognition); in teaching/learning these competing views, NOS can be demonstrated and explained in a concise and concrete way.

In Sara's post-course reflections, she stressed the importance of explicitly teaching the NOS to students, saying that "NOS needs to be taught explicitly to students for complete understanding [and] NOS is a vital concept for anyone engaged in science learning." Overall, Sara found great value in using neuroscience, a familiar science domain, to understand the complex NOS.

Sara felt as though her experiences in the catalytic group setting were drastically different from her experiences in the larger group setting. She found that in the smaller group, it was easier to share personal beliefs and experiences. In the larger group, Sara described that the conversation often "gets out of hand" because so many people share their opinions, which ends up derailing the conversations. She found it valuable and interesting to learn about the beliefs of others in the catalytic group discussions and how they connected neuroscience and the NOS. Given that Sara received extra time in a smaller group setting to interrogate the NOS and neuroscience, she felt more confident to speak up in larger group settings. She attributes this feeling to a sense of validation that she got from sharing her own perspectives in the catalytic group setting. Overall, Sara found that neuroscience was a particularly useful tool for better understanding the NOS, and she recommends it to others.

Overview. Given Sara's substantial background in neuroscience, it is interesting to note how her perspectives of the NOS changed during the course. Sara used this course to meta-cognitively reflect on her own understandings of the NOS, how those understandings are changing and what influences that change, and how neuroscience can provide a model for NOS instruction in classrooms. Sara described how she previously saw science as a sealed and static answer about natural phenomena. As a result of this course, Sara began to see how neuroscience acts as a contemporary science story, where this story provides a concrete and explicit example for understanding the NOS. She found that the competing views in neuroscience provide an interesting way to understand the inherent subjectivity of science. Sara also emphasized that not only do students need to learn the NOS in classrooms, but that neuroscience may provide a concrete and relevant example for understanding the NOS. Sara believed that type of explicit example of the NOS would be especially helpful for students who have never learned the NOS as a component of science.

Sara used a social constructivist perspective to reflect on her own understanding of the NOS and science. She commented that her understanding of the NOS is almost an 'opinion', because it is influenced by her past experiences, prior knowledge, cultural values, etc. She found her own understanding to have largely shifted as a result of the new information she encountered during this course. She also carried this social constructive perspective with her when she described science as a human endeavor. She described how the science laboratory is a subjective inquiry process carried out by humans. She also described the subjectivity of observations and inferences, describing how any data that requires descriptions are inherently biased because they are a part of the human endeavor. Sara believed that this bias arises from the personal beliefs, norms, and values that scientists carry with them into their practice.

Sara felt very positively that neuroscience was a productive and meaningful context to understand tenets of the NOS. She attributes much of her changing perspectives on the integration of neuroscience and the NOS to the time she spent in the catalytic group setting. She found that this time allowed her to hear the perspectives of others and share her own ideas, giving her validation on the ways in which she integrated neuroscience with her perspective of the NOS. Sara described how neuroscience is a newer field relative to other sub-paradigms of science and that it is constantly changing, it provides a good example to understand the NOS in an explicit and concrete way. Sara found that using neuroscience allowed for her to better understand the fluid and subjective character of the NOS through concrete examples of the principles of the NOS as they are manifested in the sub-domain of neuroscience. Sara also reflected on the possibility that in future years, neuroscience may no longer be the best model to understand the NOS. She described how in the future, there may be substantial shifts in other areas of science that provide for a more fruitful model to explain the complex NOS, while neuroscience may not be changing much in the future. Nevertheless, Sara found that neuroscience in this course was extremely beneficial for understanding exactly how the NOS manifests in the science discipline.

Cross-Comparative Analysis of Cases

The three cases presented in the study represent a variety of ways in which neuroscience and the NOS can be integrated into one cohesive understanding of the science discipline. Each case differs in terms of how this integration occurred for a variety of personal, professional, and science discipline-based reasons. The variation in case perspectives as a result of participation in the 4-week course can be realized through a theoretical framework of conceptual change. Conceptual change describes how learners change their conceptions of various entities based on the intelligibility, plausibility, and fruitfulness of the new conception presented in the learning experience (Pintrich *et al*., 1993). Additionally, the learner must feel the need for a new conception of an entity, as their current conception does not fully describe the nature and characteristics of said entity**.** For the new concept to be accepted by the learner, the new concept must be understandable by the learner (intelligibility), it must be linked to their understandings of similar entities (plausibility), and it must be able to explain new scenarios with conviction (fruitfulness). It becomes clear through the evidence from the three cases that there were several mediating factors for successful integration of neuroscience and the NOS into one cohesive understanding of the scientific discipline.

In Case 1, Liam experienced sustained difficulty in synthesizing areas of his own content knowledge understanding to the practice of science that he describes as elemental to the NOS. He has developed an understanding of the NOS such that he can describe its tentativeness and subjectivity based on personal knowledge of the cultural values and norms that differ among people. He also found that this sort of subjectivity influences what science is important in society, where society ultimately dictates the science that gets published. He did not, however, critically look at neuroscience, or his own content area expertise, through a lens of the NOS. He claimed that he always could see the NOS in biology. However, this claim ran counter to his discussions in the catalytic group, where he explicitly mentioned that biology has not changed in the last 50 years. Additionally, as a result of the course, Liam maintained his traditional views toward scientific experiments, claiming that these sorts of experiments have multiple quantifiable variables and are objective in nature. This idea ran counter to his descriptions of the sociocultural views of science that Liam holds. Liam felt strongly that this course was suitable for other teachers who seek to integrate their views of the NOS with neuroscience, but he did not think that the course clarified the abstract tenets of the NOS. Lastly, although Liam agreed with the utility of neuroscience and the NOS in classroom curricula, he held negative views toward integrating NOS and neuroscience as a way to clarify the tenets of NOS.

Liam initially thought that it made sense to use neuroscience as a platform for developing a deeper understanding of the NOS. However, it is clear from the results that Liam did not find this integration to come easy; he generally claimed that the NOS was present in biology, and that he could "see it", but he resorted to a more traditional view of science when engaged in deeper discussions of the NOS. He maintained his belief that scientific experiments have multiple quantifiable variables, and that other forms of experiments are not "true science". This perspective of science largely stemmed from his experiences conducting experiments as a biology researcher. However, he used both personal experiences as a person of color and some aspects of his biology research experience to make claims about how social and cultural norms influence what science is available to the public and how this drives the science research that is being done. He struggled to integrate these two perspectives on the NOS in addition to seeing how these perspectives are exhibited in neuroscience. As a result, Liam was unable to see the fruitfulness of connecting neuroscience and the NOS, nor did he find this connection plausible. In his post-course survey, Liam indicated that it would have been helpful to know more about neuroscience prior to connecting neuroscience and the NOS, indicating that his understanding of neuroscience (intelligibility) played a large role in his ability to integrate the domain with the NOS. It is important to note, however, that although his conceptions of the NOS took on two different perspectives, Liam was able to develop a more eloquent sociocultural perspective of the

NOS, where he could draw on specific examples from his biology research experiences as examples of this form of the NOS. Although he struggled to connect neuroscience and NOS, his conception of the NOS, generally, grew as a result of this course.

Jackson (Case 2) utilized the course to look at the NOS from a different perspective. In this course, Jackson was able to integrate his own Earth science research experiences with the neuroscience covered in this course. This connection provided a bridge, which allowed Jackson to connect his understandings of the NOS to neuroscience. Jackson used this course to reflect on both the positive and negative aspects of teaching the NOS in classrooms, largely focusing on whether teaching the NOS through its abstract tenets was an accurate reflection of how scientists truly operate. Jackson argued that the NOS really should be taught to students through a philosophical perspective that describes the traditional tenets of the NOS, but that this philosophical perspective should run parallel to conversations about how scientists actually think about and carry out scientific research. Alternatively, he did not find that students would benefit from its inclusion in school-based curricula, especially in Earth sciences. Given Jackson's background in Earth Science and desire to be an Earth Science Educator, he does not see the utility of including neuroscience in his curriculum. He did, however, see the utility of neuroscience as a platform for developing a deeper understanding of the NOS, generally, where this understanding of the NOS could be applied to classroom practice.

The data presented in Case 2 illustrates how Jackson saw a link between his current conceptions of Earth sciences research practices and the neuroscience discussed in this course. He found that his new understanding of neuroscience spoke to his Earth science research experiences with conviction, giving insight into how and why he engaged in the various research practices that he described in the catalytic group discussions. In other words, Jackson saw the intelligibility, plausibility, and fruitfulness of connecting neuroscience with Earth sciences research practices. As a result of Jackson's ability to make this connection, he also found that neuroscience provided a useful platform to further interrogate his own understandings of the NOS, generally. He came to the course with many questions on the differences between a "scientist-like experience" versus the philosophical definitions of the NOS, illustrating his clear need for a new conception of the NOS. This course allowed him to conceptually change how he viewed NOS in addition to the ways in which the NOS should be presented to his students.

In Case 3, Sara approached the integration of neuroscience and the NOS in a manner quite different from Jackson and Liam. Instead of focusing on the mindset of the scientist and how this may or may not align to the way philosophers conceptualize the NOS as in Jackson's case, Sara chose to look at the general characteristics of neuroscience as a whole represent a contemporary science story. In this way, Sara described how neuroscience is a newer field that was constantly changing and is very subjective, as science is a human endeavor. As a result, Sara found that neuroscience provided a very useful model for looking at the more abstract nature of the scientific discipline from a philosophical perspective. Additionally, Sara emphasized that this model would be a good way to teach her students about the NOS, especially if they have never previously learned the NOS. Moreover, Sara used this course to reflect on her own meta-cognitive perceptions of the NOS and neuroscience. She described how her understanding of the NOS is also subjective and tentative, because it is influenced by her own beliefs and societal norms. She recognized tenets of the NOS in her own understanding of science and neuroscience as a result of this course.

Given Sara's extensive background in neuroscience, it was easier for her to use her own understandings of science to integrate neuroscience and the NOS into one cohesive understanding of science. In the beginning of the course, it was easy for Sara to see how neuroscience could be described as a contemporary science story because neuroscientific theories are constantly changing as new evidence arises and is interpreted. In other words, when presented with the scenario of integrating neuroscience and the NOS into one understanding of the NOS, Sara was essentially primed to illustrate an increased level of intelligibility, plausibility, and fruitfulness in this approach to understanding the NOS. As the course progressed, it was evident from the results that this approach to learning the NOS helped Sara to take her new understandings of how neuroscience informs the NOS and apply them to her own understanding of the NOS and neuroscience. Sara recognized tenets of the NOS in her own understanding of the NOS and neuroscience, illustrating her meta-cognitive engagement in the course.

Discussion

The four-week course on the integration of neuroscience and the NOS represents an interesting synthesis within teacher education, resulting in evidence that the students from this course improved their general understanding of the connections that can be made between neuroscience and the NOS. Students also increased their understandings of the complex and philosophical tenets of NOS, although, as noted in prior sections, the degree of this synthesis varied among the three participants. The evidence from this case study suggests that the integration of neuroscience and the NOS can effectively improve science teachers' understandings of the NOS and the merits of synthesizing neuroscience and the NOS in a general way, but in some cases with less legitimacy relative to their science discipline. There are three areas of interest that arise from the findings of this study that should be considered when attempting to integrate neuroscience and the NOS as a platform to better understand the NOS.

First, the degree of appropriateness for the use of neuroscience in NOS instruction may be varied based on the way students understand the sub-domain of neuroscience. In other words, intelligibility of the new conception as a part of the conceptual change model is an important factor in using this context-specific platform for developing the NOS understandings. Second, if the goal of NOS instruction is to integrate the NOS understandings with one's personal science experiences, it is imperative that the context selected for NOS instruction (neuroscience, in this case) must have a perceived connection to one's own science experience. If that connection is not explicit, it should be made explicit through scaffolding activities where students are pressed to think about how neuroscience informs various scientific practices. Third, the structure of learning opportunities must have a perceived utility for students, where students believe that the learning opportunity can inform their practice as teachers. Students must see that, in this case, the integration of neuroscience with the NOS has the power to inform the way they teach their students, with regards to either the NOS or general classroom instruction.

There is considerable value in using a situated scientific context whereby students can explicitly learn and reflect on the philosophical ideas of the NOS by engaging with situations and materials that directly relate to their professional practice as educators. Selecting neuroscience as the context for an explicit-reflective approach to understanding the NOS has utility in helping students to better understand the complex nature of science. There may be an influence of familiarity with the content area (such as neuroscientific or related fields) that promotes and can perpetuate the use of the integration of neuroscience and the NOS. Other studies have found that using a relevant scientific, situated context for explicit and critical reflection on the NOS is successful, because an authentic scientific context is used for instruction and critical reflection. For example, in a literature review of the NOS, Lederman (2007) suggested that the NOS is best taught when it is embedded in a context of scientific knowledge that is relevant to students. In addition, Schwartz, Lederman, and Crawford (2004) found that the use of an authentic scientific context for critical reflection was pivotal for pre-service teachers' development of the NOS understandings. Neuroscience may be beneficial for teacher education of the NOS, especially when it is presented in a context of curriculum examples, but it is necessary that teachers view neuroscience as an intelligible entity to further understand the NOS. That is, they must have a baseline understanding of neuroscience content such that they can expand their analysis of neuroscience as a scientific field to incorporate aspects of the NOS. In this study, the ability for Liam to integrate neuroscience with the NOS was impeded by his lack of familiarity with neuroscience. This was not the case for Jackson, who was able to make personal connections between the neuroscience presented in this course and his own science research experiences as an Earth scientist.

If the goal of NOS instruction is to integrate the NOS understandings with one's personal science experiences, it is imperative that the context selected for NOS instruction (neuroscience, in this case) must have a perceived connection to one's own science experience. If that connection is not explicit, it should be made explicit through scaffolding activities where students are pressed to think about how neuroscience informs various scientific practices. Additionally, the ability to synthesize neuroscience with science content domains varies based on how learners can connect neuroscience with their own experiences in science. For students who have experience as researchers in the field of science, it may be harder for them to step out of their scientific mindset and reflect on the practices that they have previously engaged in. As a result, it may be beneficial to include aspects of meta-cognition and meta-cognitive awareness of scientific content knowledge and practices when attempting to teach prospective and in-service science teachers about the NOS. Other studies have found that pre-service students who employ specific meta-cognitive strategies such as concept mapping and investigating the development of peers' ideas, as they learn the complex nature of science through an explicit-reflective approach have more informed understandings of the NOS (Abd-El-Khalick & Akerson, 2009). Moreover, it is critical that if students struggle to connect the scientific context such as neuroscience to their own science experiences, explicit time should be devoted to making these connections. In this way, students will not be impacted by their lack of familiarity with neuroscience itself, as it would relate to other science experiences that they can then reflect on and connect to their conceptions of the NOS. Other research has shown that the use of reflection papers as a way to engage in meta-conceptual discourse had a large impact on pre-service teachers' development of informed views of the NOS (Abd-El-Khalick & Akerson, 2004). Reflection papers could be used with explicit prompts to guide students in connecting neuroscience (or any scientific context used for NOS instruction) with their own science knowledge and experiences.

Finally, it is critical that reform-oriented professional development opportunities such as the four-week course in this study must have perceived value and relevance to the professional practice of science teachers. In this way, students of such a learning opportunity will see the value of the experience and attempt to connect the information they learn with their own classroom practice. In this study, Jackson found that his understanding of the NOS as it developed in the course could be applied to his classroom. He found that a dualistic approach to teaching the NOS to students is necessary, where students think about science from a philosopher's perspective in addition to considering how scientists view their own work. Sara also found that neuroscience could be a useful model to present to students who are learning the NOS, because it is explicit the way that this contemporary science story illustrates the tenets of

NOS. Other studies have found that perceived coherence of professional development with classroom pedagogy has a higher level of effectiveness. For example, Garet *et al.* (2001) found that in-service teachers who had a perceived coherence of professional development with state standards more easily integrated information from professional development into the daily life of school. Additionally, Penuel *et al.* (2007) found that a positive perceived coherence of professional development with in-service teacher pedagogy has a positive impact on successful curricular implementation. Although in-service teachers may value the learning of neuroscience as it applies to education and learning in general, it may be necessary to provide a more scaffolded and explicit approach to using neuroscience as a way to both familiarize teachers with functions of the brain and be useful for understanding the NOS if it is to be relevant and applicable to the daily life of school.

Areas for future studies to continue this area of research in science education include considering the effectiveness of the integration of neuroscience and the NOS for the development of NOS understandings of pre-service and in-service teachers of biological sciences. Additional research includes the use of meta-cognitive strategies to help practicing scientists who desire to teach to better understand the tenets of NOS and the integration of the NOS with neuroscience. Lastly, it may be important to consider the effectiveness of a situated approach to teaching the NOS when students in those educational settings come from a variety of scientific backgrounds. It is important to note that the explicit-reflective approach is an effective strategy for NOS instruction, but it may be worth looking at making NOS instruction itself more situated, as it was presented in this four-week course, where the scientific context selected for the situated-ness is relevant and accessible to all students of the course, rather than having students use a situated context within which they individually reflect on the philosophical ideas of the NOS.

Conclusion

This study investigated the utility of neuroscience as a scientific platform for understanding the abstract tenets of the NOS. Research in teacher education has indicated that both neuroscience and the NOS have the ability to positively influence teachers' practice (Roehrig *et al*., 2012). However, neuroscience and the NOS have yet to be combined and used as an alternative approach to NOS instruction in teacher education. The four-week course presented in this study gave the opportunity to test an alternative approach for NOS instruction that could be used as a model for future professional development opportunities for in-service teachers. As such, the results from this study indicate that neuroscience provided a meaningful context for NOS instruction, especially in cases where students could connect neuroscience to aspects of their own scientific knowledge and experiences. Specifically, students found that neuroscience exemplified many of the abstract tenets of NOS in a more concrete way. This finding allowed students to reflect on their own understandings of science and the NOS in addition to more critical reflections of how scientists consider the NOS in their own professional work. Further research is warranted that could provide more explicit and meta-cognitively reflective opportunities for students, where students will be able to see the positive utility of neuroscience as a context for NOS instruction.

References

Abd-El-Khalick, F. (2001). Embedding nature of science instruction in preservice elementary science courses: Abandoning scientism, but... *Journal of Science Teacher Education*, *12*(3), 215-233.

Abd-El-Khalick, F. & Akerson, V. L. (2004). Learning as conceptual change: Factors mediating the development of preservice elementary teachers' views of the nature of science. *Science Education*, *88*(5), 101-143. doi: 10.1002/sce.10143

Abd-El-Khalick, F. & Akerson, V. L. (2009). The influence of metacognitive training on preservice elementary teachers' conceptions of the nature of science. *International Journal of Science Education*, 31(16), 2161-2184. doi: 10.1080/09500690802563324

Abd-El-Khalick, F., & Lederman, N. G. (2000). The influence of history of science courses on students' views of nature of science. *Journal of Research in Science Teaching*, *37*(10), 1057-1095. doi: 10.1002/1098-2736(200012)37:10<1057::AID-TEA3>3.0.CO;2-C

Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education*, *82*(4), 417-436.

Akerson, V. L., Abd-El-Khalick, F., & Lederman, N. G. (2000). Influence of a reflective explicit activity-based approach on elementary teachers' conceptions of nature of science. *Journal of research in Science Teaching*, *37*(4), 295-317.

Akerson, V. L., Cullen, T. A., & Hanson, D. L. (2009). Fostering a community of practice through a professional development program to improve elementary teachers' views of nature of science and teaching practice. *Journal of Research in Science Teaching*, *46*(10), 1090-1113. doi: 10.1002/tea.20303

Akerson, V. L., Morrison, J. A., & McDuffie, A. R. (2006). One course is not enough: Preservice elementary teachers' retention of improved views of nature of science. *Journal of Research in Science Teaching*, *43*(2), 194-213. doi: 10.1002/tea.20099

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32–42.

Corbetta, M., Kincade, J. M., Ollinger, J. M., McAvoy, M. P., & Shulman, G. L. (2000). Voluntary orienting is dissociated from target detection in human posterior parietal cortex. *Nature Neuroscience*, *3*(3), 292-297. doi: 10.1038/73009

Creswell, J. W. (2012). *Qualitative inquiry and research design: Choosing among five approaches.* Thousand Oaks, CA: Sage.

Duschl, R. A. & Grandy, R. (2013). Two views about explicitly teaching nature of science. *Science and Education*, *22*(9), 2109 – 2139.

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, *38*(4), 915-945.

Gilboa, A., Winocur, G., Grady, C. L., Hevenor, S. J., & Moscovitch, M. (2004). Remembering our past: Functional neuroanatomy of recollection of recent and very remote personal events. *Cerebral Cortex*, *14*(11), 1214-1225. doi: 10.1093/cercor/bhh082

Graziano, P. A., Reavis, R. D., Keane, S. P., & Calkins, S. D. (2007). The role of emotion regulation and children's early academic success. *Journal of School Psychology*, *45*(1), 3-19. doi: 10.1016/j.jsp.2006.09.002

Grossman, P., Wineburg, S., & Woolworth, S. (2001). Toward a theory of teacher community. *The Teachers College Record*, *103*, 942-1012.

Hewson, P. & Hewson, M. (1984). The role of conceptual conflict in conceptual change and the design of science instruction. *Instructional Science, 13*(1)*,* 1-13.

Hopfinger, J. B., Buonocore, M. H., & Mangun, G. R. (2000). The neural mechanisms of top-down attentional control. *Nature Neuroscience*, *3*(3), 284-291. doi: 10.1038/72999

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. New York, NY: Cambridge University Press.

Lederman, N. G. (1999). Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. *Journal of Research in Science teaching*, *36*(8), 916-929.

Lederman, N. G. (2007). Nature of science: Past, present, and future. In S.K. Abell & N. G. Lederman, (Eds.), *Handbook of Research on Science Education* (pp. 831-879). Mahwah, NJ: Erlbaum.

Liang, L. L., Chen, S., Chen, X., Kaya, O. N., Adams, A. D., Macklin, M., & Ebenezer, J. (2006, April). Student Understanding of Science and Scientific Inquiry (SUSSI): Revision and further validation of an assessment instrument. Paper presented at the *Annual Conference of the National Association for Research in Science Teaching*, San Francisco, CA.

McCabe, D. P. & Castel, A. D. (2008). Seeing is believing: The effect of brain images on judgments of scientific reasoning. *Cognition*, *107*, 343-352. doi: 10.1016/j.cognition.2007.07.017

National Research Council [NRC]. (1996). *National science education standards.* Washington DC: National Academy Press.

National Research Council [NRC]. (2011). *A framework for k-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

NGSS Lead States (2013). *Next generation science standards, for states, by states*. Washington DC: National Academy Press.

Ohman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology*, *130*(3), 466-478. doi: 10.1037/0096-3445.130.3.466

Palinscar, A. S., Magnusson, S. J., Marano, N., Ford, D., and Brown, N. (1998). Designing a community of practice: Principles and practices of the GIsML community. *Teaching and Teacher Education*, 14(1), 5-19.

Penuel, W. R., Fishman, B. J., Yamaguchi, R., & Gallagher, L. P. (2007). What makes professional development effective? Strategies that foster curriculum implementation. *American Educational Research Journal*, *44*(4), 921-958.

Roehrig, G. H., Michlin, M., Schmitt, L., MacNabb, C., & Dubinsky, J. M. (2012). Teaching neuroscience to science teachers: Facilitating the translation of inquiry-based teaching instruction to the classroom. *Cell Biology Education - Life Sciences Education*, *11*(4), 413-424. doi: 10.1187/cbe.12-04-0045

Schwartz, R.S., & Crawford, B. A. (2004). Authentic scientific inquiry as context for teaching nature of science. In L. Flick & N.G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education* (pp. 331-355). Dordrecht, Netherlands: Springer.

Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science education*, *88*(4), 610-645. doi: 10.1002/sce.10128

Serpati, L. & Loughan, A. R. (2007). Teacher perceptions of neuroeducation: A mixed methods survey of teachers in the United States. *Mind, Brain, and Education*, 6(3), 174-176.

Sylvan, L. J., & Christodoulou, J. A. (2010). Understanding the role of neuroscience in brain based products: A guide for educators and consumers. *Mind, Brain, and Education*, *4*(1), 1-7. doi: 10.1111/j.1751-228X.2009.01077.x

Takashima, A., Petersson, K. M., Rutters, F., Tendolkar, I, Jensen, O., Zwarts, M. J., McNaughton, B. L., & Fernandez, G. (2006). Declarative memory consolidation in humans: a prospective functional magnetic resonance imaging study. *Proceedings of the National Academy of Sciences of the United States of America*, *103*(3), 756-761. doi: 10.1073/pnas.0507774103

Trainor, A. A. & Graue, E. (2013). *Reviewing qualitative research in the social sciences.* New York, NY: Routledge.

Weisberg, D. S., Keil, F. C., Goodstein, J., Rawson, E., & Gray, J. R. (2008). The seductive allure of neuroscience explanations. *Journal of Cognitive Neuroscience*, *20*(3), 470-477.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge, UK: Cambridge university press.

Willingham, D. T. (2006). “Brain-based” learning: More fiction than fact. *American Educator,* 30-37.

Appendix A

Pre-Survey: Attitudes and Beliefs about NOS-Neuroscience Connections

1. Using examples from neuroscience research can be a good context for understanding the nature of science (NOS).

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

2. It may be easier to make connections between NOS and neuroscience if a teacher knows more about the neuroscientific domain.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

3. Neuroscience and NOS are disparate scientific endeavors and bear few obvious connections to one another.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

4. I am interested in the integration of NOS and neuroscience to better understand NOS concepts.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

5. I believe that it is necessary to learn NOS to be an effective science educator.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

6. It is possible to explain NOS concepts using evidence from the neurosciences as scientific examples.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

7. There is a meaningful and logical relationship between neuroscience and NOS.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

8. The many qualities of NOS are an excellent resource that should be used to better understand how scientific knowledge is developed and evolves over time.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

9. I believe that it is valuable to learn the various historical and philosophical aspects of NOS.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

10. Applying NOS principles to a science discipline that we teach is useful for developing a holistic understanding of NOS.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

11. I find learning about NOS to be a rewarding experience.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

12. In my opinion, learning about NOS can enhance my understanding of a science domain.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

<u>Post-Survey: Attitudes and Beliefs about NOS-Neuroscience Connections</u>

1. Using examples from neuroscience research can be a good context for understanding the nature of science (NOS).

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

2. It may be easier to make connections between NOS and neuroscience if a teacher knows more about the neuroscientific domain.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

3. Neuroscience and NOS are disparate scientific endeavors and bear few obvious connections to one another.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

4. I am interested in the integration of NOS and neuroscience to better understand NOS concepts.

Strongly disagree Disagree Neutral/Not Sure Agree Strongly agree
[1] [2] [3] [4] [5]

5. I believe that it is necessary to learn NOS to be an effective science educator.

Strongly disagree Disagree Neutral/Not Sure Agree Strongly agree
[1] [2] [3] [4] [5]

6. It is possible to explain NOS concepts using evidence from the neurosciences as scientific examples.

Strongly disagree Disagree Neutral/Not Sure Agree Strongly agree
[1] [2] [3] [4] [5]

7. There is a meaningful and logical relationship between neuroscience and NOS.

Strongly disagree Disagree Neutral/Not Sure Agree Strongly agree
[1] [2] [3] [4] [5]

8. The many qualities of NOS are an excellent resource that should be used to better understand how scientific knowledge is developed and evolves over time.

Strongly disagree Disagree Neutral/Not Sure Agree Strongly agree
[1] [2] [3] [4] [5]

9. I believe that it is valuable to learn the various historical and philosophical aspects of NOS.

Strongly disagree Disagree Neutral/Not Sure Agree Strongly agree
[1] [2] [3] [4] [5]

10. Applying NOS principles to a science discipline that we teach is useful for developing a holistic understanding of NOS.

Strongly disagree Disagree Neutral/Not Sure Agree Strongly agree
[1] [2] [3] [4] [5]

11. I find learning about NOS to be a rewarding experience.

Strongly disagree Disagree Neutral/Not Sure Agree Strongly agree
[1] [2] [3] [4] [5]

12. In my opinion, learning about NOS can enhance my understanding of a science domain.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

13. I feel more confident in including neuroscience and NOS in my teaching.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

14. By participating in this part of the course, I found it useful to think about integrating neuroscience ideas with NOS as a way of clarifying the meaning of NOS.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

15. I believe that students would be positively attracted to learning science when neuroscience and NOS are integrated, based on what I learned so far.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

16. Many features of NOS can be identified and exemplified in neuroscience.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

17. I would recommend that someone attempting to learn NOS could use some aspects of neuroscience to increase their understandings.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

18. As a result of this course, neuroscience has helped me to see NOS from a different perspective.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

Appendix B

Mid-Intervention Reflection Reports

1. Do the ideas in the readings we have had so far for this class fit our discussions of the nature of science (NOS)? How have your ideas about NOS changed over the course of this intervention? *In your discussion, try to focus on the elements of tentativeness, creativity, observation vs. inference, subjectivity, and relationships of theory and law.*

2. In what ways have your experiences in this intervention *(the neuroscience lectures, the lesson study, the NOS activities, and the focus group if you are in one)* impacted the attitudes that you may carry towards using neuroscience and/or NOS to inform science teaching and learning?

Appendix C

Catalytic Group Reflection Report

1. How have your experiences in the focus group contributed to your attitudes about connecting neuroscience and NOS and using those domains of knowledge in science teaching and learning?

2. How do your experiences in the normal class setting (with other students of the course) adhere to or stray from the conversations you have had in the focus groups? Is there space in the large group for you to continue the conversations that you have had in the focus group, or are these experiences largely separate from one another?

Chapter 6

DISCUSSION

The research objective of this study was to develop an alternative approach to teaching NOS through relevant topics from neuroscience and learning, with the intention of contributing this approach to teacher education. Current research in science education indicates that an explicit, reflective approach to NOS instruction is most effective (Abd-El-Khalick, 2001; Abd-El-Khalick & Lederman, 2000; Lederman, 2007; Schwartz & Crawford, 2004). It is important to use an appropriate situated context in addition to the explicit, reflective approach to encourage class participants' reflection on the more abstract aspects of NOS. A student's ability to apply their NOS understandings to novel situations (i.e., to other scientific contexts) is dependent on the scientific frame that is used for NOS instruction (Abd-El-Khalick, 2001; Clough, 2006). For example, Abd-El-Khalick (2001) suggested that the context within which students learn NOS affects their ability to apply NOS understandings to novel contexts. Additionally, Clough (2006) suggests that the use of contemporary science stories provide for useful examples of NOS in that they illustrate science-in-the-making and desensitize students to media reports of science. Clough (2006) suggest that media reports of science are often quite beneficial for teaching NOS, as they illustrate the subjective and changing nature of scientific knowledge. As a result, Clough (2006) suggests that a situated approach to NOS instruction should utilize a situated scientific context that is familiar to students either through the use of content that is widely available from public sources such as the media or based on previous academic study.

In this study, neuroscience was used as the situated context for NOS instruction. Neuroscience was selected for use in NOS instruction based on the findings of Clough (2006), who suggest that a science that has a large media presence, such as neuroscience, can be fruitful for NOS instruction. While neuroscience did not serve as a context fully familiar to all students in terms of their previous academic study, it served as an area of study that has previously positively benefited teacher pedagogy (Roehrig *et al.*, 2012). Neuroscience is not only relevant to teacher pedagogy because it deals with the workings of the brain, but also it is a contemporary science story; it illustrates science in the making. This intervention is different from previously published NOS initiatives in teacher education, because an explicit, reflective approach for NOS instruction was coupled with teaching-relevant neuroscience topics, where the goal was to explicitly address NOS conceptions. In this way, neuroscience provided a context for understanding the NOS in a way that pushes back against the established norms of the scientific discipline. Additionally, this intervention utilized a novel organization of the learning activities that included a whole-class set of sessions augmented by input from two smaller student-led catalytic groups (three students each), whose function was to meet separately between whole group sessions, reflect on the connection of NOS with the educationally-relevant neuroscience topics, and be prepared to stimulate whole-class discussion in the next class meeting. This protocol was selected as a way to test an alternative model that varies from an established model, where students' beliefs that are expressed during small-group discussions are not necessarily used to inform instruction in larger class settings (Alexopoulou & Driver, 1996; Smith *et al.*, 2009). In the model utilized in this intervention, the role of participants in the catalytic group was to raise interesting questions with the whole class, and to share ideas from their smaller group meetings. In the subsequent sections, the major findings in Chapters 4 and 5 will be analyzed through a cross-comparative discussion of the major findings, including relationships to prior published research. Thereafter, gains and limitations of the current study are discussed, followed by suggestions for future research.

Cross-Comparative Discussion of the Findings

Three common themes were established through the findings of each chapter that are suggested. First, neuroscience can serve as a productive scientific context for NOS instruction, even when students are not necessarily familiar with neuroscience based on their previous academic study. However, the use of neuroscience as a situated context for NOS-relevant education must be evaluated in the context of the teacher's disciplinary focus (e.g., biology or other natural sciences). For neuroscience to be a fruitful platform for NOS instruction, it is critical that students see the ways in which NOS manifests in neuroscience, and then transfer those insights to their own scientific expertise. Second, adequate time for critical reflection, both individually and in small groups, was pivotal for the successful development of NOS understandings and synthesis of neuroscience and NOS. Third, the catalytic groups that define the alternative model for NOS instruction used in this study positively benefitted catalytic group members. Their work, while limited in some respects, considerably heightened participants' ability to synthesize neuroscience and NOS, and encouraged the participants to reflect on their own understandings, thereby increasing their understanding of NOS at a more general level.

Neuroscience as an approach to NOS Instruction

The evidence from this research study showed that curriculum-relevant, neuroscience topics can be used as a valuable situated context to promote student reflection on some of the more abstract tenets of NOS. Thus, using a situated context for reflection may have continued importance for the learner as they progress in further learning about NOS, and can play a larger role in the success of students in synthesizing NOS with a specific science domain as they gain additional insights about the relationship of NOS to the teaching of science. Additionally, the use of a situated context has increased perceived value in the professional education of teachers when they engage with situations and materials that most closely relate to classroom practice.

Clough (2006) reasoned that students can be inhibited in their development of a deep understanding of NOS if they are unfamiliar with the science content that is related to NOS. However, this unfamiliarity can be mitigated if the instructor uses contemporary science stories that have a large media presence. Neuroscience was selected for its high level of presence in the current media, generally, and in education through brain-based products. The findings of this study indicated that the selection of neuroscience as the context for situated learning was more meaningful for students who were better able to synthesize their own science experiences with the neuroscience they learned during this study. This synthesis helped students to streamline their understandings of NOS across their own science knowledge, thereby increasing their ability to transfer NOS knowledge to different scientific contexts. There did not exist the issue of neuroscience acting as a barrier to NOS learning due to a lack of familiarity with neuroscience itself, as Clough (2006) suggest. Rather, students' development of NOS conceptions was more largely based on their ability to see the similarities of the neuroscience context to their own science learning experiences through their understanding of NOS.

A second factor that influenced students' development of NOS conceptions was the relatability of NOS to classroom practice. Based on the evidence presented in this research study, it seems as though, despite the large media presence of neuroscience, only certain topics within neuroscience are of interest to science teachers and have a closer connection to daily classroom practice. For example, the first neuroscience topic, 'neuroscience of memory', had a more direct connection to teacher pedagogy and participants were more successful in integrating neuroscience and NOS. However, this success realized with this first neuroscience topic was not sustained in subsequent sessions, and the students' capacity to integrate NOS and the neuroscience topics steadily declined over the course of the intervention. This was particularly the case when they were challenged to synthesize the neuroscience of attention and of emotion with NOS. The initial topic on the neuroscience of memory provided a 'hook' in that it was directly relatable to teacher pedagogy, and as a result, participants' general unfamiliarity with the topic of memory in learning facilitated their ability to use neuroscience of memory to better understand NOS. As a result, simply being familiar with neuroscience through its media presence may not be enough to provide a sufficiently well-developed understanding to promote integration with NOS. As such, it may be beneficial to include aspects of the history of science or science and technology studies (STS) as way to bridge this gap in connecting a specific science domain with the tenets of NOS for students who are not familiar with the specific scientific context used for NOS instruction. Moreover, in retrospect, it may have been more productive to determine initially just how much prior experience the participants in the class had with media-based topics on neuroscience in learning. This is another note of caution that future researchers need to keep in mind as they attempt to innovation novel connections between the NOS and specialized areas of science that are related to curricula and learning.

Time for Critical Reflection

The findings from this study indicated that an explicit, reflective approach to teaching NOS is valuable for students who are learning NOS. The evidence from the participants in this study indicated that the added time for reflection on their own understandings of NOS and their science experiences were necessary and pivotal in developing their conceptions of NOS. Multiple participants noted how there was not added time during in-class instruction for the interrogation of their own thoughts, but that the reflection reports helped them to analyze their own understandings, which positively influenced their learning. Furthermore, participants who described how they benefitted from added time for critical reflections also explained how this time was valuable in their journey to better understand NOS. Including aspects of metacognition and self-awareness may influence the ability for students to integrate their knowledge of the epistemologies that guide scientific practice with their science experiences, allowing them to reflect on those experiences through a lens of NOS. Abd-El-Khalik and Akerson (2009) found that providing structured opportunities for critical reflection on NOS 'forced' students to think about and clarify their own understandings of NOS, and students reported that these opportunities were the most helpful activity that influenced their views on NOS. This study also found a similar result, in that students highly valued time for critical reflection and found it to be one of the more useful activities in the study.

Additionally, it is necessary for teachers to pay explicit attention to the cognitive factors that influence learning NOS through a traditional conceptual change approach. Helping students to integrate their own conceptions of science with NOS can be quite difficult, as many students have little to no experience considering the philosophies that describe the scientific discipline. As a result, they may not see the need for a change in their conceptions of science to include the tenets of NOS. Thus, explicit attention to the cognitive factors that promote a 'deep processing' orientation towards learning may be beneficial to help students to develop more informed and elaborate views of NOS. Abd-El-Khalik and Akerson (2009) reported that although time for critical reflection was reported as the most useful strategy for changing conceptions of NOS, this change was higher among students who had a 'deep processing' orientation towards learning. That is, students who sought to clarify the meaning of NOS and apply aspects of NOS to multiple science contexts while monitoring their own views of NOS developed more informed views of NOS. The use of a science context to understand NOS, while it is scaffolded with metacognitive strategies for learning, may help foster a disposition for 'deep processing' during learning that can contribute to a deeper understanding of NOS. It may also be beneficial to develop scaffolded activities for students that help them to connect their own science experiences with NOS. These activities would help students to see the need for understanding the tenets of NOS as they apply to their own science understandings, thus helping those students to develop a 'deep processing' orientation toward learning NOS.

Small Group Discourse

A summary of the findings from the interviews with the catalytic group members is presented here. Further findings of their relationship to the larger whole group of participants is presented later.

The findings from the interviews with members of the catalytic groups indicated that the opportunity for small-group discourse positively impacted participants' development of elaborate conceptions of NOS. Catalytic group participants reported that their small-group discourse was more intimate and allowed them to reflect on their own conceptions of science. Moreover, they believed that they were able to connect their conceptions of NOS in a more dynamic way, rather than passively learn the conceptions of NOS as presented by the instructor. The catalytic group activities provided an opportunity for participants to engage in a community-based critical reflection through guided discourse, where NOS was addressed explicitly and reflectively in the learning environment. Providing such a smaller catalytic group for discourse also facilitated the development of a socially constructed meaning of NOS, thereby helping students to develop more elaborate conceptions of NOS rooted in their own beliefs and experiences about science. In other words, students' discussions about NOS and experiences connecting NOS to their own science understandings informed the development of a shared understanding of what NOS is and how it is applied to multiple scientific contexts. The opportunity for work in smaller catalytic groups provided sub-communities of practice within the larger community, which allowed for more voices to be heard in a more equal balance and helped participants to define their own conceptions of NOS. These findings from the catalytic group activities aligned with the findings of Schwartz et al. (2004), who found that during learning about NOS, there should be an opportunity for guided discourse among the learners in addition to writing activities that are intended to encourage critical reflection. These opportunities for shared discourse among the learners were critical for NOS conceptual development within a scientific context (Schwartz et al., 2004). Additionally, Schwartz et al. (2004) maintained that NOS should be a cognitive outcome where it is addressed explicitly and reflectively in the learning environment.

Role of the Catalytic Groups During the Whole-group Sessions

Catalytic group participants' participation in the large group lesson setting differed from the intended role of the catalytic group. Participants were reluctant to share out their discussion points from the smaller group setting, despite being given explicit time to develop a summary of main points and questions that they wanted to share with the larger group. The reflection report evidence indicated that some of the catalytic group members did not feel confident in sharing their discussion points with the larger group. However, their participation in the catalytic group discussion often helped them feel a sense of confidence when engaging in activities guided by the instructor during the large group sessions. For example, students felt more confident speaking out in the larger group when the group was pressed to consider how neuroscience explicitly exemplifies the tenets of NOS. Additionally, students felt more confident when pressed to connect science experiences with NOS, acting as an example for other students in the course who may have initially struggled to connect these ideas. As a result, the catalytic group worked well for those participants, in that their own confidence to engage with neuroscience-based curriculum activities related to NOS increased over time in addition to developing informed views of NOS. However, because the catalytic group members did not share their discussion points and questions with the larger group, these results are limited to those who engaged in the catalytic group discussions, rather than actually acting as a catalytic force to increase NOS understanding for the larger group.

Further research with regards to the use of catalytic groups within larger class settings are warranted in terms of investigating a different strategy for presenting the role of the catalytic group member to participants in addition to the goal of the catalytic group itself. This role should be considered an opportunity to further question and investigate the ways in which neuroscience and NOS could be coupled with one another through a discussion where skeptical perspectives on their connection are welcomed, shared, and further discussed and investigated. Special attention should be paid to creating a set of questions that could be brought back to the larger group which debate the fruitful connections that could be made between neuroscience and NOS.

Reflection on the Gains and Limitations of the NOS Instructional Approach

Generally, the novel NOS instructional approach had a valuable and positive impact on the participants in this research study. Opportunities for critical reflection at multiple levels (i.e., individually, in catalytic groups, and in the large group lesson setting) allowed for a meaningful and personally-situated development of participants' understanding of NOS. The intervention approach provided an opportunity to garner clarity in participants' understandings of NOS as they developed over the four-week intervention. I would recommend the use of this novel approach for NOS instruction, albeit there are some suggestions for its future use as an instructional approach.

The catalytic group discussions added a layer of support for students to reflect on their own understandings of NOS and how those understandings were changing over the course of the study. The opportunity for small-group discussion helped participants gain some clarity in their own understandings of NOS and feel validated in their discomfort in knowing that their previously held beliefs about science were beginning to change. In future studies, it would be beneficial to make the goal of the catalytic group more explicit for small-group members. In an effort to preserve the integrity of the study, the goal of the catalytic group was made implicit for participants. However, the goal for the catalytic group must be made explicit where the facilitator is direct in terms of how the discussion in the catalytic group setting will promote discussion in the larger group. Catalytic group members should be tasked with creating a collective list of questions that they would like to pose to the larger group for further discussion.

The use of neuroscience as a situated approach for NOS instruction proved useful for neuroscience topics that were more closely related to teacher pedagogy. In other words, neuroscience was more valuable as a situated context for NOS instruction when the neuroscience topic was highly related to classroom practice. As a result, a more useful approach to using neuroscience as a context for NOS instruction may specifically focus on one neuroscience topic, e.g., neuroscience of memory, and its classroom implications, rather than attempt to give participants a broad understanding of multiple areas of learning-related neuroscience topics. Additionally, participants were familiarized with neuroscience topics via ‘mini-lectures’ presented by the researcher, which provided a foundation from which participants could use that platform to interrogate conceptions of NOS. These mini-lectures utilized a direct instruction approach during the large group lesson setting, and this may have partially ameliorated some of the cognitive demands placed on the participants in dealing with the complexities of applying neuroscience to teaching and learning of science.

Future instructional applications of this approach should also consider providing alternative opportunities for participants to familiarize themselves with neuroscience, either as a pre-session homework activity or through enrollment in another course that is closely related to neuroscience of memory, such as cognition or cognitive psychology. Then, the added time during the large group sessions could be spent on other collaborative activities, such as a lesson study or a share-out of discussion questions from catalytic group meetings. Lastly, it may be of value to have participants learn aspects of cognition or cognitive psychology prior to engaging in the learning of neuroscience. In this way, cognition or cognitive psychology could act as a stepping stone for understanding how neuroscience can inform behavioral output that might be seen in the classroom. Learners would then be provided enough content and background knowledge to be able to critically analyze neuroscience through a NOS perspective.

Future Research

Areas for future research are suggested based on the three findings of the cross-comparative analysis as indicated in the previous section. Moreover, attention is given to aspects of the intervention that were effective, including advice on possible changes that should be made for future research to build on the initial insights gained through this first attempt at synthesizing NOS and neuroscience topic. Lastly, recommendations to create better-designed studies in the future are discussed based on what has been learned in this initial attempt of using this model for NOS instruction.

Future Research Based on Cross-Comparative Findings

The evidence from the research study provides insight into multiple ways to meaningfully navigate the use of this novel approach to NOS instruction in future research. There are two areas that can be more explicitly addressed based on the findings of this study: (1) the use of metacognitive strategies and a meta-investigation of cognitive factors that influence learning, and (2) the inclusion of more catalytic groups drawn from the entire group of participants in this novel approach to instruction.

With respect to the first area addressed above, it may be necessary to develop highly scaffolded activities for students to develop the skillset of investigating their own beliefs and experiences in addition to helping them become more aware of the epistemologies that they hold about science. For students that are enrolled in a course on NOS, this may be the first time where they are beginning to question their own past science experiences, and thus there should be support in place during instruction to help students begin to think in a meta-cognitive fashion about the science that they know and experience. To investigate this phenomenon, evidence could be collected via the use of surveys that address metacognitive theories in addition to inquiry-based activities that could be incorporated into NOS instruction. If the meta-cognitive survey is used in a pre-post format, it could be coupled with a pre-post NOS survey, where one could investigate the utility of using metacognitive strategies during situated-based NOS instruction.

With respect to the merits of catalytic groups, it may be beneficial for all students in the larger group who are engaged in this novel approach to NOS instruction to engage in a catalytic kind of group meeting, in addition to the stimulatory role of some designated smaller catalytic groups. Based on the interview evidence from the two catalytic groups used in this study, these small-group meetings allowed for all participants in the small group to have a voice, and it enhanced the opportunity for participants to synthesize their own understandings of science with that of others in the group in addition to integrating their understandings of NOS tenets that they learn as the course progresses. These small groups, assembled from the class as a whole, should focus on making NOS an explicit goal for reflective discussion, where participants are tasked with developing a set of questions that arose during their discussion that they would like to bring back to the larger group. It should be made explicit that the list of questions developed in the small group session will be presented by the participants of that small group in the larger group lesson setting, with the opportunity for all large group participants to discuss the posed questions.

Furthermore, it may be of interest to include more catalytic groups into this instructional approach, so that each large group participant is assigned to a catalytic group and is provided the opportunity for small-group reflection and discussion. In this way, all participants would have the opportunity for multiple layers of critical reflection on NOS and could contribute the developing, shared understanding of NOS as it developed over the course of opportunities for discussion. Because all large-group members would also participate in a small group discussion setting, more time should then be devoted to discussing the questions from the catalytic groups during the large group lesson setting. Evidence should be gathered that focuses on observations of the integration of catalytic groups with the larger group lesson setting, where special attention is paid to how participants integrate their discussions from the catalytic group meetings as a guide for larger group discussions. Additional interviews with participants could address how they chose to share their experiences from the catalytic groups in the larger lesson setting. Furthermore, content analysis could be used to investigate the common themes and questions that emerge in the catalytic group discussions, which would then be cross-analyzed with the larger group lesson setting observations.

Lastly, when considering the role of professional development in science education and science teacher education, it may be interesting to utilize the concept of the catalytic groups as an added layer of support for in-service teacher PD. Recent research on the role of professional learning communities (PLC's) indicates that smaller groups focused on the connections between student learning and teaching practice have a positive effect on teachers' pedagogy (Vescio, Ross, & Adams, 2007). PLC's often are characterized by a reform-oriented approach, where the focus of conversations in these PLC's are situated within the lived experiences of teachers in their classrooms. Teachers also engage in critical reflections, where they consider the connections between curriculum, instruction, and student development. A more intimate approach to utilizing PLC's as a part of in-service teacher PD may consider smaller groups (3-4) of teachers who engage in critical dialogues, and then share these dialogues with the larger teaching staff, where these share-outs are used to inform curriculum and instruction.

References

Abd-El-Khalick, F. (2001). Embedding nature of science instruction in preservice elementary science courses: Abandoning scientism, but... *Journal of Science Teacher Education*, *12*(3), 215-233.

Abd-El-Khalick, F. & Akerson, V. L. (2004). Learning as conceptual change: Factors mediating the development of preservice elementary teachers' viewbs of the nature of science. *Science Education*, *88*(5), 101-143. doi: 10.1002/sce.10143

Abd-El-Khalick, F. & Akerson, V. L. (2009). The influence of metacognitive training on preservice elementary teachers' conceptions of the nature of science. *International Journal of Science Education*, *31*(16), 2161-2184. doi: 10.1080/09500690802563324

Abd-El-Khalick, F. & BouJaoude, S. (1997). An exploratory study of the knowledge base for science teaching. *Journal of Research in Science Teaching*, *34*(7), 673-699. doi: 10.1002/(SICI)1098-2736(199709)34:7<673::AID-TEA2>3.0.CO;2-J

Abd-El-Khalick, F., & Lederman, N. G. (2000). The influence of history of science courses on students' views of nature of science. *Journal of Research in Science Teaching*, *37*(10), 1057-1095. doi: 10.1002/1098-2736(200012)37:10<1057::AID-TEA3>3.0.CO;2-C

Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education*, *82*(4), 417-436.

Aguirre, J. M., Haggerty, S. M., & Linder, C. J. (1990). Student-teachers' conceptions of science, teaching, and learning: a case study in preservice science education. *International Journal of Science Education*, *12*(4), 381 – 390. doi: 10.1080/0950069900120405

Aikenhead, G. S. & Jegede, O. J. (1999). Cross-cultural science education: A cognitive explanation of a cultural phenomenon. *Journal of Research in Science Teaching*, *36*(3), 269-287.

Akerson, V. L., Abd-El-Khalick, F., & Lederman, N. G. (2000). Influence of a reflective explicit activity-based approach on elementary teachers' conceptions of nature of science. *Journal of research in Science Teaching*, *37*(4), 295-317.

Akerson, V. L., Cullen, T. A., & Hanson, D. L. (2009). Fostering a community of practice through a professional development program to improve elementary teachers' views of nature of science and teaching practice. *Journal of Research in Science Teaching*, *46*(10), 1090-1113. doi: 10.1002/tea.20303

Akerson, V. L., Morrison, J. A., & McDuffie, A. R. (2006). One course is not enough: Preservice elementary teachers' retention of improved views of nature of science. *Journal of Research in Science Teaching*, *43*(2), 194-213. doi: 10.1002/tea.20099

Alexopoulou, E., & Driver, R. (1996). Small-group discussion in physics: Peer interaction modes in pairs and fours. *Journal of Research in Science Teaching*, *33*(10), 1099-1114.

American Association for the Advancement of Science. [AAAS] (1990). *Science for all Americans.* New York, NY: Oxford University Press.

American Association for the Advancement of Science. [AAAS] (1993). *Benchmarks for science literacy*. New York, NY: Oxford University Press.

Anderson, O. R. (1997). A neurocognitive perspective on current learning theory and science instructional strategies. *Science Education*, *81*(1), 67-89. doi: 10.1002/(SICI)1098-237X(199701)81:1<67::AID-SCE4>3.0.CO;2-#

Anderson, O. R. (2014). Progress in application of the neurosciences to an understanding of human learning: The challenge of finding a middle-ground neuroeducational theory. *International Journal of Science and Mathematics Education*, *12*(3), 475-492.

Ansari, D., Coch, D., & De Smedt, B. (2011). Connecting education and cognitive neuroscience: Where will the journey take us? *Educational Philosophy and Theory*, *43*(1), 37-42. doi: 10.1111/j.1469-5812.2010.00705.x

Atherton, M., & Diket, R. (2005). Applying the neurosciences to educational research: Can cognitive neuroscience bridge the gap? Part I. In *Annual Meeting of the American Educational Research Association. Montreal, Canada*.

Ball, D. L. & Cohen, D. K. (1996). Reform by the book: what is – or might be – the role of curriculum materials in teacher learning and instructional reform?. *Educational Researcher*, *25*(9), 6-14.

Barnett, J. & Hodson, D. (2001). Pedagogical context knowledge: Toward a fuller understanding of what good science teachers know. *Science Teacher Education*, *85*(4), 426-453. doi: 10.1002/sce.1017

Bell, R. L., Lederman, N. G., & Abd-El-Khalick, F. (2000). Developing and acting upon one's conception of the nature of science: A follow-up study. *Journal of Research in Science Teaching*, *37*(6), 563-581.

Bernardon, F. (2013). When neuroscience guides education. *Science*, 342(6159), 671. doi: 10.1126/science.342.6159.671-b

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist*, *26*(3-4), 369-398. doi: 10.1080/00461520.1991.9653139

Boaler, J. (1997). Reclaiming school mathematics: The girls fight back. *Gender and Education*, *9*(3), 285-305. doi: 10.1080/09540259721268

Boeije, H. (2009). *Analysis in qualitative research*. Thousand Oaks: Sage.

Bottge, B. A. (1999). Effects of contextualized math instruction on problem solving of average and below-average achieving students. *The Journal of Special Education*, *33*(2), 81-92.

Bottge, B. A., Heinrichs, M., Chan, S. Y., & Serlin, R. C. (2001). Anchoring adolescents' understanding of math concepts in rich problem-solving environments. *Remedial and Special Education*, *22*(5), 299-314.

Bower, G. H., Monteiro, K. P., & Gilligan, S. G. (1978). Emotional mood as a context for learning and recall. *Journal of Verbal Learning and Verbal Behavior*, *17*(5), 573-585. doi: 10.1016/S0022-5371(78)90348-1

Brickhouse, N. W. (1990). Teachers' beliefs about the nature of science and their relationship to classroom practice. *Journal of Teacher Education*, *41*(3), 53-62.

Brown, B. A. (2004). Discursive identity: Assimilation into the culture of science and its implications for minority students. *Journal of Research in Science Teaching*, *41*(8), 810-834. doi: 10.1002/tea.20228

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32–42.

Brown, B. A., Reveles, J. M., & Kelly, G. J. (2005). Scientific literacy and discursive identity: A theoretical framework for understanding science learning. *Science Education*, *89*(5), 779-802. doi: 10.1002/sce.20069

Bruer, J. T. (1997). Education and the brain: A bridge too far. *Educational Researcher*, *26*(8), 4-16.

Cahill, L., Babinsky, R., Markowitsch, H. J., & McGaugh, J. L. (1995). The amygdala and emotional memory. *Nature*, *377*(6547), 295-296. doi: 10.1038/377295a0

Cakiroglu, J., Cakiroglu, E., & Boone, W. J. (2005). Pre-service teacher self-efficacy beliefs regarding science teaching: A comparison of pre-service teachers in Turkey and the USA. *Science Educator*, *14*(1), 31.

Cantrell, P., Young, S., & Moore, A. (2003). Factors affecting science teaching efficacy of preservice elementary teachers. *Journal of Science Teacher Education*, *14*(3), 177-192.

Carey, R. L., & Stauss, N. G. (1968). An analysis of the understanding of the nature of science by prospective secondary science teachers. *Science Education*, *52*(4), 358-363. doi: 10.1002/sce.3730520410

Cash, J. R., Behrmann, M. B., Stadt, R. W., & Daniels, H. M. (1997). Effectiveness of cognitive apprenticeship instructional methods in college automotive technology classrooms. *Journal of Industrial Teacher Education, 34*(2), 29-49.

Charney, J., Hmelo-Silver, C. E., Sofer, W., Neigeborn, L., Coletta, S., & Nemeroff, M. (2007). Cognitive apprenticeship in science through immersion in laboratory practices. *International Journal of Science Education*, *29*(2), 195-213. doi: 10.1080/09500690600560985

Chi, M. T., Slotta, J. D., & de Leeuw, N. (1994). From things to processes: A theory of conceptual change for learning science concepts. *Learning and Instruction*, *4*(1), 27-43. 10.1016/0959-4752(94)90017-5

Cho, M. H., Lankford, D. M., & Wescott, D. J. (2011). Exploring the relationship among epistemological beliefs, nature of science, and conceptual change in the learning of evolutionary theory. *Evolution: Education Outreach*, *4*(2), 313-322.

Clough, M. (2006). Learners' responses to the demands of conceptual change: Considerations for effective nature of science instruction. *Science Education*, *15*(1), 463-494.

Cognition and Technology Group at Vanderbilt. (1992). Anchored instruction in science and mathematics: Theoretical basis, developmental projects, and initial research findings. In R. A. Duschl & R. J. Hamilton (Eds.), *Philosophy of science, cognitive psychology, and educational theory and practice* (pp. 244–273). Albany, NY: SUNY Press.

Collins, A., Brown, J. S., & Holum, A. (1991). Cognitive apprenticeship: Making thinking visible. *American Educator, 15*(3), 6 – 11.

Corbetta, M., Kincade, J. M., Ollinger, J. M., McAvoy, M. P., & Shulman, G. L. (2000). Voluntary orienting is dissociated from target detection in human posterior parietal cortex. *Nature Neuroscience*, *3*(3), 292-297. doi: 10.1038/73009

Creswell, J. W. (1999). Mixed-method research: Introduction and application. In Cizek, G. J. (Ed.), *Handbook of Educational Policy* (pp. 455-472). San Diego, CA: Academic Press.

Creswell, J. W. (2012). *Qualitative inquiry and research design: Choosing among five approaches.* Thousand Oaks, CA: Sage.

Darling-Hammond, L. (2000). How teacher education matters. *Journal of Teacher Education*, 51(3), 166-173.

Darling-Hammond, L. & McLaughlin, M. W. (1995). Policies that support professional development in an era of reform. *Phi Delta Kappan*, *76*(8), 597.

Daselaar, S. M., Rice, H. J., Greenberg, D. L., Cabeza, R., LaBar, K. S., & Rubin, D. C. (2008). The spatiotemporal dynamics of autobiographical memory: Neural correlates of recall, emotional intensity, and reliving. *Cerebral Cortex*, *18*(1), 217-229. 10.1093/cercor/bhm048

DeBoer, G. E. (1991). *A history of ideas in science education: Implications for practice*. New York, NY: Teachers College Press.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*(7), 5-12.

Dubinsky, J. M. (2010). Neuroscience education for prekindergarten–12 teachers. *Journal of Neuroscience*, *30*(24), 8057-8060. doi: 10.1523/JNEUROSCI.2322-10.2010

Duschl, R. A. & Grandy, R. (2013). Two views about explicitly teaching nature of science. *Science and Education*, *22*(9), 2109 – 2139.

Duncan, S. L. S. (1996). Cognitive apprenticeship in classroom instruction: Implications for industrial and technical teacher education. *Journal of Industrial Teacher Education*, 33(3), 66-86.

Duschl, R. A. (1990). *Restructuring science education: The importance of theories and their development*. New York, NY: Teachers College Press.

Duschl, R. A. & Grandy, R. (2013). Two views about explicitly teaching nature of science. *Science and Education*, *22*(9), 2109 – 2139.

Etheris, A. I., & Tan, S. C. (2004). Computer-supported collaborative problem solving and anchored instruction in a mathematics classroom: an exploratory study. *International Journal of Learning Technology*, *1*(1), 16-39. doi: 10.1504/IJLT.2004.003680

Ferrari, M. (2011). What can neuroscience bring to education? *Educational Philosophy and Theory*, *43*(1), 31-36. doi: 10.1111/j.1469-5812.2010.00704.x

Fishman, B. J., Marx, R. W., Best, S., & Tal, T. R. (2003). Linking teacher and student learning to improve professional development in systemic reform. *Teaching and Teacher Education*, *19*, 643-658. doi: 10.1016/S0742-051X(03)00059-3

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal*, *38*(4), 915-945.

Geake, J. (2004). Cognitive neuroscience and education: Two-way traffic or one-way street? *Westminster Studies in Education, 27*(1), 87-98. doi: 10.1080/0140672040270107

Geake, J. & Cooper, P. (2003). Cognitive neuroscience: Implications for education? *Westminster Studies in Education*, *26*(1), 7-20. doi: 10.1080/0140672030260102

Geier, R., Blumenfeld, P. C., Marx, R. W., Krajcik, J. S., Fishman, B., Soloway, E., & Clay-Chambers, J. (2008). Standardized test outcomes for students engaged in inquiry-based science curricula in the context of urban reform. *Journal of Research in Science Teaching*, *45*(8), 922-939. doi: 10.1002/tea.20248

Gilboa, A., Winocur, G., Grady, C. L., Hevenor, S. J., & Moscovitch, M. (2004). Remembering our past: Functional neuroanatomy of recollection of recent and very remote personal events. *Cerebral Cortex*, *14*(11), 1214-1225. doi: 10.1093/cercor/bhh082

Godden, D. R., & Baddeley, A. D. (1975). Context-dependent memory in two natural environments: On land and underwater. *British Journal of Psychology*, *66*(3), 325-331. doi: 10.1111/j.2044-8295.1975.tb01468.x

Goldin, P. R., Manber-Ball, T., Werner, K., Heimberg, R., & Gross, J. J. (2009). Neural mechanisms of cognitive reappraisal of negative self-beliefs in social anxiety disorder. *Biological Psychiatry*, *66*(12), 1091-1099. doi: 10.1016/j.biopsych.2009.07.014

Goodwin, D. W., Powell, B., Bremer, D., Hoine, H., & Stern, J. (1969). Alcohol and recall: State-dependent effects in man. *Science*, *163*(3873), 1358-1360. doi: 10.1126/science.163.3873.1358

Goswami, U. (2006). Neuroscience and education: From research to practice? *Nature Reviews Neuroscience*, *7*(5), 406-413. doi: 10.1038/nrn1907

Graziano, P. A., Reavis, R. D., Keane, S. P., & Calkins, S. D. (2007). The role of emotion regulation and children's early academic success. *Journal of School Psychology*, *45*(1), 3-19. doi: 10.1016/j.jsp.2006.09.002

Grossman, P., Wineburg, S., & Woolworth, S. (2001). Toward a theory of teacher community. *The Teachers College Record*, *103*, 942-1012.

Handley, K., Sturdy, A., Fincham, R., & Clark, T. (2006). Within and beyond communities of practice: Making sense of learning through participation, identity and practice. *Journal of Management Studies*, *43*(3), 641-653. doi: 10.1111/j.1467-6486.2006.00605.x

Hardiman, M., Rinne, L., Gregory, E., & Yarmolinskaya, J. (2012). Neuroethics, neuroeducation, and classroom teaching: Where the brain sciences meet pedagogy. *Neuroethics*, *5*(2), 135-143.

Hendricks, C. C. (2001). Teaching causal reasoning through cognitive apprenticeship: What are results from situated learning?. *The Journal of Educational Research*, *94*(5), 302-311. doi: 10.1080/00220670109598766

Hewson, P. & Hewson, M. (1984). The role of conceptual conflict in conceptual change and the design of science instruction. *Instructional Science, 13*(1)*,* 1-13.

Holland, A. C., & Kensinger, E. A. (2010). Emotion and autobiographical memory. *Physics of Life Reviews*, *7*(1), 88-131. doi: 10.1016/j.plrev.2010.01.006

Hopfinger, J. B., Buonocore, M. H., & Mangun, G. R. (2000). The neural mechanisms of top-down attentional control. *Nature Neuroscience*, *3*(3), 284-291. doi: 10.1038/72999

Irez, S. (2006). Are we prepared? An assessment of preservice science teacher educators' beliefs about nature of science. *Science Education*, *90*(6), 1113-1143. doi: 10.1002/sce.20156

Jelinek, D. J. (1998, April). Student perceptions of the nature of science and attitudes towards science education in an experiential science program. Paper presented at the *Annual Meeting of the National Association for Research in Science Teaching,* San Diego, CA.

Kanter, D. E. (2010). Doing the project and learning the content: Designing project-based science curricula for meaningful understanding. *Science Education*, *94*(3), 525-551. doi: 10.1002/sce.20381

Kim, P., Evans, G. W., Angstadt, M., Ho, S. S., Sripada, C. S., Swain, J. E., Liberzon, I., & Phan, K. L. (2013). Effect of childhood poverty and chronic stress on emotion regulatory brain function in adulthood. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(46), 18442-18447. doi: 10.1073/pnas.1308240110

Klopfer, L. & Cooley, W. (1961). *Test on Understanding Science, Form W*. Princeton, NJ: Educational Testing Service.

Klopfer, L. E., & Cooley, W. W. (1963). The history of science cases for high schools in the development of student understanding of science and scientists: A report on the HOSG instruction project. *Journal of Research in Science Teaching*, *1*(1), 33-47. doi: 10.1002/tea.3660010112

Koenig, K., Schen, M., & Bao, L. (2012). Explicitly targeting pre-service teacher scientific reasoning abilities and understanding of nature of science through an introductory science course. *Science Educator*, *21*(2), 1-9.

Krajcik, J. & Blumenfeld, P. (2006). Project-based learning. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (pp. 317-333). New York, NY: Cambridge University Press.

Krajcik, J., Blumenfeld, P. C., Marx, R. W., Bass, K. M., Fredricks, J., & Soloway, E. (1998). Inquiry in project-based science classrooms: Initial attempts by middle school students. *Journal of the Learning Sciences*, *7*(3-4), 313-350. doi: 10.1080/10508406.1998.9672057

Kubitskey, B., & Fishman, B. J. (2006, June). A role for professional development in sustainability: Linking the written curriculum to enactment. In *Proceedings of the 7th International Conference on Learning Sciences* (pp. 363-369). International Society of the Learning Sciences, Bloomington, IN.

Kuhn, T. S. (2012). *The Structure of Scientific Revolutions*. Chicago, IL: University of Chicago Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. New York, NY: Cambridge University Press.

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching*, *29*(4), 331-359. doi: 10.1002/tea.3660290404

Lederman, N. G. (1999). Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. *Journal of Research in Science Teaching*, *36*(8), 916-929.

Lederman, N. G. (2007). Nature of science: Past, present, and future. In S.K. Abell & N. G. Lederman, (Eds.), *Handbook of Research on Science Education* (pp. 831-879). Mahwah, NJ: Erlbaum.

Lemke, J. L. (1997). Cognition, context, and learning: A social semiotic perspective. In D. Kirshner (Ed.), *Situated Cognition: Social, Semiotic, and Psychological Perspectives* (pp. 37-56). Mahwah, NJ: Erlbaum.

Lemke, J. L. (2002). Language development and identity: Multiple timescales in the social ecology of learning. In C. Candlin & S. Sarangi (Eds.), *Language Acquisition and Language Socialization* (pp. 68-87). New York, NY: Bloomsbury.

Liang, L. L., Chen, S., Chen, X., Kaya, O. N., Adams, A. D., Macklin, M., & Ebenezer, J. (2006, April). Student Understanding of Science and Scientific Inquiry (SUSSI): Revision and further validation of an assessment instrument. Paper presented at the *Annual Conference of the National Association for Research in Science Teaching*, San Francisco, CA.

Lincoln, Y.S. & Guba, E.G. (1985). *Naturalistic Inquiry*. Newbury Park, CA: Sage Publications.

Luehmann, A. L. (2007). Identity development as a lens to science teacher preparation. *Science Education*, *91*(5), 822-839. doi: 10.1002/sce.20209

MacNabb, C., Brier, G., Teegarten, J., Schmitt, L., Drager, N., Thomas, L., Dubinsky, J.M. (2006). Lessons. BrainU website. http://brainu.org/lessons (accessed 21 January, 2017).

Magnusson, S. J., Borko, H., & Krajcik, J. S. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. Lederman (Eds.), *Examining Pedagogical Content Knowledge* (pp. 95-132). Boston, MA: Kluwer Press.

McCabe, D. P. & Castel, A. D. (2008). Seeing is believing: The effect of brain images on judgments of scientific reasoning. *Cognition*, *107*, 343-352. doi: 10.1016/j.cognition.2007.07.017

McComas, W. F., Clough, M. P., & Almazroa, H. (1998). The role and character of the nature of science in science education. In W.F. McComas (Ed.), *The nature of science in science education: Rationales and Strategies* (pp. 3–39). Dordrecht, Netherlands: Springer.

Mesci, G., & Schwartz, R. S. (2016). Changing preservice science teachers' views of nature of science: Why some conceptions may be more easily altered than others. *Research in Science Education*, *47*(2), 329-351.

Mensah, F. M. (2009). Confronting assumptions, biases, and stereotypes in preservice teachers' conceptualizations of science teaching through the use of book club. *Journal of Research in Science Teaching*, *46*(9), 1041-1066. doi: 10.1002/tea.20299

Meyer, D. K., Turner, J. C., & Spencer, C. A. (1997). Challenge in a mathematics classroom: Students' motivation and strategies in project-based learning. *The Elementary School Journal, 97*(5), 501-521.

Moss, D. M., Abrams, E. D., & Kull, J. A. (1998). Can we be scientists too? Secondary students' perceptions of scientific research from a project-based classroom. *Journal of Science Education and Technology*, *7*(2), 149-161.

Nadel, L., Samsonovich, A, Ryan, L., & Moscovitch, M. (2000). Multiple trace theory of human memory: computational, neuroimaging, and neuropsychological results. *Hippocampus*, *10*(4), 352 – 368. doi: 10.1002/1098-1063(2000)10:4<352::AID-HIPO2>3.0.CO;2-D

National Research Council [NRC]. (1996). *National science education standards.* Washington DC: National Academy Press.

National Research Council [NRC]. (2000a). *Effective teaching: Examples in history, mathematics, and science*. In J. D. Bransford, A. L. Brown, & R. R. Cocking, (Eds.), *How people learn: Brain, mind, experience, and school: Expanded edition* (pp. 155-189). National Academies Press.

National Research Council [NRC]. (2000b). Teacher Learning. In J. D. Bransford, A. L. Brown, & R. R. Cocking, (Eds.), *How people learn: Brain, mind, experience, and school: Expanded edition* (pp. 190-205). National Academies Press.

National Research Council [NRC]. (2011). *A framework for k-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

NGSS Lead States (2013). *Next generation science standards, for states, by states*. Washington DC: National Academy Press.

Ochsner, K. N., Ray, R. D., Cooper, J. C., Robertson, E. R., Chopra, S., Gabrieli, J. D., & Gross, J. J. (2004). For better or for worse: Neural systems supporting the cognitive down-and up-regulation of negative emotion. *Neuroimage*, *23*(2), 483-499. doi: 10.1016/j.neuroimage.2004.06.030

Ohman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology*, *130*(3), 466-478. doi: 10.1037/0096-3445.130.3.466

Palincsar, A. S. (1998). Social constructivist perspectives on teaching and learning. *Annual Review of Psychology*, *49*(1), 345-375. doi: 10.1146/annurev.psych.49.1.345

Palinscar, A. S., Magnusson, S. J., Marano, N., Ford, D., and Brown, N. (1998). Designing a community of practice: Principles and practices of the GIsML community. *Teaching and Teacher Education*, 14(1), 5-19.

Penuel, W. R., Fishman, B. J., Yamaguchi, R., & Gallagher, L. P. (2007). What makes professional development effective? Strategies that foster curriculum implementation. *American Educational Research Journal*, *44*(4), 921-958.

Pickering, S. J., & Howard-Jones, P. (2007). Educators' views on the role of neuroscience in education: Findings from a study of UK and international perspectives. *Mind, Brain, and Education*, *1*(3), 109-113. doi: 10.1111/j.1751-228X.2007.00011.x

Pintrich, P., Marx, R., & Boyle, R. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 63*(2), 167-199.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*(1), 3-25. doi: 10.1080/00335558008248231

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, *66*(2), 211-227. doi: 10.1002/sce.3730660207

Purdy, N., & Morrison, H. (2009). Cognitive neuroscience and education: Unravelling the confusion. *Oxford Review of Education*, *35*(1), 99-109.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning?. *Educational Researcher*, *29*(1), 4-15.

Roehrig, G. H., Michlin, M., Schmitt, L., MacNabb, C., & Dubinsky, J. M. (2012). Teaching neuroscience to science teachers: facilitating the translation of inquiry-based teaching instruction to the classroom. *Life Sciences Education*, 11, 413-424.

Roth, W. M., Eijck, M. V., Hsu, P. L., Marshall, A., & Mazumder, A. (2009). What high school students learn during internships in biology laboratories. *The American Biology Teacher*, *71*(8), 492-496.

Rowe, M. B. (1974). A humanistic intent: The program of preservice elementary education at the University of Florida. *Science Education*, *58*(3), 369-376. doi: 10.1002/sce.3730580311

Ryan, A. G., & Aikenhead, G. S. (1992). Students' preconceptions about the epistemology of science. *Science Education*, *76*(6), 559-580.

Schraw, G., Crippen, K. J., & Hartley, K. (2006). Promoting self-regulation in science education: Metacognition as part of a broader perspective on learning. *Research in Science Education*, *36*(1-2), 111-139.

Schwartz, R.S., & Crawford, B. A. (2004). Authentic scientific inquiry as context for teaching nature of science. In L. Flick & N.G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education* (pp. 331-355). Dordrecht, Netherlands: Springer.

Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education*, *88*(4), 610-645. doi: 10.1002/sce.10128

Serafino, K., & Cicchelli, T. (2003). Cognitive theories, prior knowledge, and anchored instruction on mathematical problem solving and transfer. *Education and Urban Society*, *36*(1), 79-93.

Serpati, L. & Loughan, A. R. (2007). Teacher perceptions of neuroeducation: A mixed methods survey of teachers in the United States. *Mind, Brain, and Education*, 6(3), 174-176.

Shepherd, H. G. (1998). The probe method: A problem-based learning model's effect on critical thinking skills of fourth- and fifth-grade social studies students (doctoral dissertation). Retrieved from https://www.learntechlib.org/p/117976/.

Shulman, L. S. (1986). Those who understand: Knowledge and growth in teaching. *Educational Researcher*, *15*(2), 4-14.

Shyu, H. Y. C. (2000). Using video-based anchored instruction to enhance learning: Taiwan's experience. *British Journal of Educational Technology*, *31*(1), 57-69. doi: 10.1111/1467-8535.00135

Smith, M. K., Wood, W. B., Adams, W. K., Wieman, C., Knight, J. K., Guild, N., & Su, T. T. (2009). Why peer discussion improves student performance on in-class concept questions. *Science*, *323*(5910), 122-124.

Sylvan, L. J., & Christodoulou, J. A. (2010). Understanding the role of neuroscience in brain based products: A guide for educators and consumers. *Mind, Brain, and Education*, *4*(1), 1-7. doi: 10.1111/j.1751-228X.2009.01077.x

Takashima, A., Petersson, K. M., Rutters, F., Tendolkar, I, Jensen, O., Zwarts, M. J., McNaughton, B. L., & Fernandez, G. (2006). Declarative memory consolidation in humans: a prospective functional magnetic resonance imaging study. *Proceedings of the National Academy of Sciences of the United States of America*, *103*(3), 756-761. doi: 10.1073/pnas.0507774103

Tamir, P. (1972). Understanding the process of science by students exposed to different science curricula in Israel. *Journal of Research in Science Teaching*, *9*(3), 239-245. doi: 10.1002/tea.3660090309

Trainor, A. A. & Graue, E. (2013). *Reviewing qualitative research in the social sciences.* New York, NY: Routledge.

Treisman, A. M. (1969). Strategies and models of selective attention. *Psychological Review*, *76*(3), 282-299. doi: 10.1037/h0027242

Trent, J. (1965). The attainment of the concept "understanding science" using contrasting physics courses. *Journal of Research in Science Teaching*, *3*(3), 224-229. doi: 10.1002/tea.3660030309

Tsai, C. C. (2010). Nested epistemologies: Science teachers' beliefs of teaching, learning, and science. *International Journal of Science Education, 24*(8), 771 – 783. doi: 10.1080/09500690110049132

Tulving, E., & Psotka, J. (1971). Retroactive inhibition in free recall: Inaccessibility of information available in the memory store. *Journal of Experimental Psychology*, *87*(1), 1-8.

Varma, S., McCandliss, B. D., & Schwartz, D. L. (2008). Scientific and pragmatic challenges for bridging education and neuroscience. *Educational Researcher*, *37*(3), 140-152.

Vescio, V., Ross, D., & Adams, A. (2008). A review of research on the impact of professional learning communities on teaching practice and student learning. *Teaching and Teacher Education*, *24*(1), 80-91.

Weisberg, D. S., Keil, F. C., Goodstein, J., Rawson, E., & Gray, J. R. (2008). The seductive allure of neuroscience explanations. *Journal of Cognitive Neuroscience*, *20*(3), 470-477.

Welch, W. W., & Walberg, H. J. (1972). A national experiment in curriculum evaluation. *American Educational Research Journal*, *9*(3), 373-383.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge, UK: Cambridge university press.

Wenger, E. (2000). Communities of practice and social learning systems. *Organization*, *7*(2), 225-246. doi: 10.1177/135050840072002

Williams Glaser, C., Reith, H. J., Kinzer, C. K., Prestige, L., K., & Peter, J. (1999). A description of the impact of multimedia anchored instruction on classroom interactions. *Journal of Special Education Technology, 14*(2)*,* 27 – 43.

Willingham, D. T. (2006). "Brain-based" learning: More fiction than fact. *American Educator,* 30-37.

Willingham, D. T. (2009). Three problems in the marriage of neuroscience and education. *Cortex*, *45*(4), 544-545.

Wilson, S. M. & Berne, J. (1999). Teacher learning and the acquisition of professional knowledge: An examination of research on contemporary professional development. *Review of Research in Education*, *24*(1), 173-209.

Wortham, S. (2003). Accomplishing identity in participant-denoting discourse. *Journal of Linguistic Anthropology*, *13*(2), 189-210. doi: 10.1525/jlin.2003.13.2.189

Wortham, S. (2004). From good student to outcast: The emergence of a classroom identity. *Ethos*, *32*(2), 164-187. doi: 10.1525/eth.2004.32.2.164

Appendices

Appendix A: IRB Approval Letter

TEACHERS COLLEGE
COLUMBIA UNIVERSITY

Teachers College IRB *Expedited Approval Notification*

To: Kristina Hopkins
From: Myra Luna-Lucero
Subject: IRB Approval: 17-406 Protocol
Date: 08/07/2017

Please be informed that as of the date of this letter, the Institutional Review Board for the Protection of Human Subjects at Teachers College, Columbia University has given full approval to your study, entitled "*Pre-Service Teachers' Applications of the Nature of Science To Teacher Pedagogy Through the Situation of Neuroscience Within the Context of Daily Classroom Practice*," under **Expedited Review** (Category **(6) Collection of data from voice, video, digital, or image recordings made for research purposes.**
(7) Research on individual or group characteristics or behavior) on 08/07/2017.

The approval is effective until **08/06/2018**.

The IRB Committee must be contacted if there are any changes to the protocol during this period. **Please note:** If you are planning to continue your study, a Continuing Review report must be submitted to either close the protocol or request permission to continue for another year. Please submit your report by **07/09/2018** so that the IRB has time to review and approve your report if you wish to continue your study. The IRB number assigned to your protocol is **17-406**. Feel free to contact the IRB Office (212-678-4105 or irb@tc.edu) if you have any questions.

Please note that your Consent form bears an official IRB authorization stamp and is attached to this email. Copies of this form with the IRB stamp must be used for your research work. Further, all research recruitment materials must include the study's IRB-approved protocol number. You can retrieve a PDF copy of this approval letter as well as the stamped consent(s) and recruitment materials from the IRB Mentor site.

When your study ends, please visit the IRB Mentor site. Go to the Continuing Review tab and select "terminate" from the drop-down menu.

Best wishes for your research work.

Sincerely,
Myra Luna-Lucero

irb@tc.edu

Attachments:
- Class Observation Consent - Final Changes.pdf
- Informed Consent_Focus Group_Final Changes.pdf

Appendix B: Script for Participant Recruitment

Script for the Announcement of the Research Study

This script is to be presented to the students enrolled in MSTC 5041 on the first day of the course alongside the PowerPoint Presentation:

Slide 1

My name is Kristina Hopkins, and I am a fourth-year PhD candidate in the program of science education, and I am beginning my dissertation research this semester. The current title of my dissertation is "Pre-Service Teachers' Applications of the Nature of Science to Teacher Pedagogy Through the Situation of Neuroscience within the Context of Daily Classroom Practice". In more simplistic terms, for my research, I am looking at how the nature of science can be better understood using a more specific scientific context, namely neuroscience, and how that specific scientitic context affects the ways in which pre-service teachers understand and plan for the nature of science as it applies to the classroom.

Slide 2

The reason why I am conducting this study is because a large focus of science education research on NOS reflects a lack of transference of NOS knowledge that PST's gain during their teacher preparation programs to their classroom practice. There are some tricks of the trade that have been established over the decades of research that have been performed on this topic to provide better instruction for PST's on NOS, but there is not a consistent, successful pattern of transference of NOS to lesson planning or pedagogy. So in my work, my objective is to establish a more consistent pattern of transference of NOS to lesson planning by grounding NOS in the scientific sub-field of neuroscience.
My overarching research question, which is actually broken up into 4 sub-questions that I will not identify here, is: does neuroscience serve as a fruitful foundation for PST's to learn about NOS as it applies to classroom practice? Because I am looking at a specific population, pre-service teachers who are enrolled in a course on the nature of science, I have been granted approval from the instructor and the IRB Office to use this course for my research.

Slide 3

You are eligible to participate in this study if you are enrolled in the science education program at TC, you are enrolled in the nature and practices of science (MSTC 5041) where you have not taken this course before this semester.

Slide 4

Students in this course (you all) have the possibility to participate in my project in two different ways. First, there will be large-group sessions during the assigned time when this course is supposed to meet, where we all come together and investigate different neuroscientific concepts and participate in a lesson study, where we look at how certain neuroscience topics can be taught to K-12 students. These large group meetings will take place during normal class time. There will also be a small group of (hopefully) 6 students that will meet in triads to take these neuroscientific findings and relate them to the concepts of the nature of science that you have learned so far during the course. These groups will meet outside of class time for about one hour. Because small groups participate in this research project outside of class, the instructor has decided to waive the final paper presentation requirement for this course. If you are interested in participating as a focus group participant, please let me know via email.

Slide 5

If you are a large group participant, you will be required to complete 4 surveys over a 4 week span that take about 30 minutes each, The SUSSI, Student Understanding of Science and Scientific Inquiry, will be filled out once before the study and once after the study. The demographic survey will be filled out before the intervention. The Attitudes/Beliefs survey and the Follow-up class Participation survey will be filled out once before and once after the intervention occurs. In addition to completing all the tasks of the large group, you will also write one two-page reflection papers in response to these small group sessions, and fill out a series of questions during these one-hour small group sessions (this is labeled as the focus group facilitation guide).

Slide 6

You can see here that this study will take place over the course of 4 weeks. Large group sessions will occur weekly, on the day and time in which this class normally meets. Focus group participants will also meet once a week, in between large group sessions. So the 1st small group meeting occurs after the 1st large group session but prior to the 2nd large group session. This is because focus-group participants will be responsible for bringing the points discussed in the small groups back to the large group for discussion. You can also see where I have labeled when the tasks that you are responsible for will take place. The demographic survey, the Attitudes/Beliefs survey, and the SUSSI are taken prior to the 1st large group session. For focus-group participants, you will fill out a facilitation guide and write a summative reflection paper to correspond with the two focus group meetings that will take place. After the 4th and final session is complete, you will take the follow-up survey, the SUSSI (again), and the Attitudes/Beliefs Survey.

Slide 7

Here, you can see where the research study fits into the syllabus. You will still follow all normal weekly readings and class participation, in addition to the blue items in red for large group participants and items in both red and blue for focus group participants.

Slide 8

For large group sessions, the first hour will be devoted to neuroscience and lesson planning. For the first 20 minutes or so, I will lecture you on a particular neuroscience topic. We then will move into a 30-minute lesson study of an inquiry-based activity to teach K-12 students this neuroscience topic. We will then transition into a 1-hour discussion of the articles that you read for the week, where students from the class will volunteer to lead instruction, per the normal protocol of how this class runs according to the instructor. In the 2nd, 3rd, and 4th sessions, the class schedule will be modified to fit in the discussion points from the small group meetings. During these two hours, a research assistant will be observing and recording any statements and/or interactions you have with one another.

Slide 9

There are three main neuroscience topics to be covered during this 4-week intervention – memory, attention, and emotion regulation. These topics relate to NOS topics that you will read about for each week. These readings are listed in your syllabus.

Slide 10

As small-group participants, you will participate in two one-hour discussion sessions facilitated by the researcher. In these sessions, you will be given a document with three broad questions to help frame your discussions. At the end of each session you will compile a list of main points and/or questions that you would like to bring back to the next large group session.

Slide 11

This study will take approximately 4 weeks to complete. You are able to leave the study at any time, even if you have not finished, and this will not affect your course grade. This study has minimal risks, including the triggering of emotions or feelings of discomfort if conversations pick up topics of race and/or culture in science and science education. You do not have to answer any questions that you do not want to talk about. As necessary the instructor, the course assistant, and/or myself will refer you to Columbia Health Services for further examination.

Slide 12

The data from this study will not be collected anonymously. I will keep all documents on my personal computer, locked with a password. I will destroy all paper copies after they are scanned and logged into my computer. You may ask for copies of your own work at any time. I am using participant numbers which you will be aware of, to keep track of the data I collect. To write my dissertation, I will use pseudonyms, so that in case any of you read my dissertation after it is published in the Library Reserves, you will not be able to identify any participants in the study.

Slide 13

There are no direct benefits for large group participants in this study. However, there are two benefits for focus-group participants, including monetary remunerations and final paper presentation examinations.

Slide 14

If you are willing and able to consent, you must sign a consent form that is approved by the IRB Office. As a large-group participant you will sign the Class Observation Consent form. As a focus-group participant, you will sign the Focus Group Consent Form in addition to the Class Observation consent form. If you are not willing and/or able to consent, or you do not qualify for this study, you will not be penalized in any way related to course grading. You are still able to come to all regular class sessions and participate in all activities and class discussions. Any statements and/or interactions that you have with other students regardless of their participation status will not be recorded. I am now going to pass around to you an informed consent form that you must sign if you are willing to engage in my research study. In this consent form, you will be able to re-read the information that I presented to you today. If you are not willing or able to participate in this study, or if you do not qualify based on your degree program or teaching experience, please do not sign this form.

Appendix C: Outline of the Presentation for Participant Recruitment

1. Purpose and Objectives of the Study
    a. Why is this study being done?
        i. A large implication of PST's learning of NOS is that they will carry over these understandings to their classrooms as they enter the field of education
        ii. Current teaching of the nature of science in graduate schools does not allow for consistent, successful transference of NOS to lesson planning or teacher pedagogy
        iii. Grounding the nature and practices of science in a scientific context (neuroscience) may allow for greater transference to instructional practice
    b. What is the objective?
        i. To determine if neuroscience provides an appropriate and productive scientific context to better understand the nature and practices of science
    c. Research Question
        i. Does neuroscience serve as a fruitful foundation for pre-service teachers to learn about the nature of science as it applies to classroom practice?
2. Eligibility for Participation
    a. You are eligible if:
        i. You are enrolled in MSTC 5041 and you have not taken this class before
        ii. You are not participating in another research study concurrently
3. Two Roles for Participation
    a. Large Group Participant
        i. 4 Large Group sessions that take place during this assigned class time
            1. (Wednesdays from 5-7 pm)
        ii. 3 surveys to complete either before or after the intervention
        iii. Lesson plan analyses to take place during the normal class sessions
    b. Focus Group Participant
        i. Complete all tasks of Large group participants, plus:
            1. 2 Focus Group sessions that take place outside of class time
                a. (1 hour sessions, TBD by members of the group)
                b. Eligible for exemption from the final course presentation if you attend both sessions
                c. Remunerations for Metro fares if you choose to meet on any day that you are not normally on campus
4. The Intervention Format
    a. Showed a figure of the intervention format including all large group and focus group sessions and documentation that will be collected along the way
5. Large Group Session Format
    a. 0-5 min.: settle-in/announcements
    b. 5-25 min.: Mini-lecture – neuroscience topic
    c. 25-55 min.: Lesson Study – inquiry-based lesson demonstrating the neuroscience topic
    d. 55-100 min.: NOS Discussion – based on NOS articles assigned for the week
6. Small Group Session Format
    a. 1-hour, discussion-based sessions facilitated by the researcher

    b. In these sessions you will answer three broad questions that are listed on the facilitation guide that I will give you
    c. At the end of these sessions, you will compile a list of main points and/or questions that you would like to bring back to the next Large Group Session
7. Duration of the Study
    a. This study will take approximately 4 weeks.
    b. You are able to leave the study at any time even if you have not finished (this will not affect your course grade.)
    c. This study has minimal risks, including:
        i. The triggering of emotions or feelings of discomfort as this topic of conversation may include conversations related to race and diversity in science and science education
        ii. You may feel uncomfortable or embarrassed in discussing how the culture of science has traditionally alienated the cultures that you most strongly identify with. You do not have to answer any questions or divulge anything you don't want to talk about.
    d. You can stop participating in the study at any time without penalty.
    e. As necessary, the researcher, instructor, and/or course assistant will refer you to Columbia Health Services
8. Anonymity and Surveillance of this Study
    a. All materials collected as data for this study will be scanned and uploaded to a password-protected computer owned by the researcher.
    b. Any tangible (i.e. written on paper) documents will be destroyed after they are collected, scanned and uploaded to said computer.
    c. You may ask for copies of your responses at any time, and they will be sent to you electronically.
    d. A record of real names, pseudonyms, and participant numbers will be kept on this password-protected computer separate from the data.
        i. Pseudonyms will be used to complete the writing of the dissertation (participants will not know their assigned pseudonyms.)
        ii. Participant numbers will be used to collate and analyze the data (participants will be aware of their own assigned numbers.)
9. Benefits of this Study
    a. For Large Group participants:
        i. There is no direct benefit from participating in this study.
        ii. However, there are potential intellectual benefits from this study. This study also has the potential to benefit the field of science education and science teacher preparation.
    b. For Focus Group participants:
        i. Final paper presentation exemptions
            1. The professor of MSTC 5041 and the researcher have agreed that in exchange for added time spent outside of class participating in this research study, you will not have to present your final course paper. Participation in this focus group will count toward your class participation in lieu of this final presentation.
10. Consent Materials

a. If you are willing and able, and qualify to participate in this study, you must sign a consent form, titled *Class Observation Consent* prior to the start of the study or before you do anything related to the data that will be collected for this study.
b. If you are willing to participate in the focus group sessions, you must also sign an additional consent form, titled *Focus Group Consent* prior to the start of the first focus group session.

Appendix D: Assigned Readings for NOS course

Week 1 September 6 Introduction to the Course

No assigned readings

Week 2 September 13 What is science?

Ziman, J. (2000). Real Science: What It Is, and What It Means. Cambridge, UK: Cambridge University Press. Chapter 1 (p.1-11).

Aikenhead, G. S. & Jegede, O. J. (1999). Cross-cultural science education: A cognitive explanation of a cultural phenomenon. *Journal of Research in Science Teaching*, *36*(3), 269-287.

Week 3 September 20 "Normal" science

Kuhn, T. (1962/2012). The Structure of Scientific Revolutions. Chicago: University of Chicago Press. Chapters 2-6.

Week 4 September 27 Scientific Revolutions

Kuhn, T. (1962/2012). The Structure of Scientific Revolutions. Chicago: University of Chicago Press. Chapters 7-12.

Week 5 October 4 Nature of Science and Education

McComas, W. F., Clough, M. P., & Almazroa, H. (2002). The role and character of the nature of science in science education. In *The nature of science in science education* (pp. 3-39). Springer Netherlands.

Lederman, N. G. (2007). Nature of science: Past, present, and future. *Handbook of Research on Science Education*, 831-879.

Week 6 October 11 Science as Social Curation

Latour, B., & Woolgar, S. (1979). Laboratory Life: The Social Construction of Scientific Facts. Princeton University Press. Chapter 2: p. 43-90.

Longino, H. E. (1990). Science as social knowledge: Values and objectivity in scientific inquiry. Princeton University Press. Chapter 4: p. 62-82.

Neuroscience Topic 1

Week 7 October 18 Science Laboratory in Context

Hofstein, A., & Kind, P. M. (2012). Learning in and from science laboratories. In *Second international handbook of science education* (pp. 189-207). Springer Netherlands.

Lemke, J. L. (2001). Articulating communities: Sociocultural perspectives on science education. *Journal of Research in Science Teaching*, *38*(3), 296-316.

Neuroscience Topic 2

Week 8 October 25 Epistemologies in Science

Kelly, G. J., McDonald, S., & Wickman, P. O. (2012). Science learning and epistemology. In *Second international handbook of science education* (pp. 281-291). Springer Netherlands.

Hammer, D. (1994). Epistemological beliefs in introductory physics. *Cognition and Instruction, 12*(2), 151-183.

Week 9 November 1 Multicultural and Feminist Science

Cobern, W. W., & Loving, C. C. (2001). Defining "science" in a multicultural world: Implications for science education. *Science Education, 85*(1), 50-67.

Brickhouse, N. (2001). Embodying science: A feminist perspective on learning. *Journal of Research in Science Teaching, 38*(3), 282-295.

Calabrese Barton, A. (1997). Liberatory science education: Weaving connections between feminist theory and science education. *Curriculum Inquiry, 27*(2), 141-163.

Neuroscience Topic 3

Week 10 November 8 The NGSS and Science Literacy

Lee, O. (1997). Scientific literacy for all: What is it and how can we achieve it? *Journal of Research in Science Teaching, 34*(3), 219-222.

National Research Council. (2011). *A Framework for K-12 Science Education.* Washington, D.C.: National Academy Press. Chapters 1-4.

Neuroscience Topic Review

Week 11 November 15 Modeling in Science

Lehrer, R., & Schauble, L. (2006). Cultivating model-based reasoning in science education. *Cambridge handbook of the learning sciences*, 371-388.

Schwarz, C.V., Reiser, B.J., Davis, E.A., Kenyon, L., Achér, A., Fortus, D., … Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching, 46*(6), 632-654.

Week 12 November 23 THANKSGIVING

NO CLASS

Week 13 November 29 Argumentation in Science

Ford, M. (2008). Disciplinary authority and accountability in scientific practice and learning. *Science Education, 92*(3), 404-423.

Bricker, L. A., & Bell, P. (2008). Conceptualizations of argumentation from science studies and the learning sciences and their implications for the practices of science education. *Science Education, 92*(3), 473-498.

Berland, L.K., & McNeill, K.L. (2010). A learning progression for scientific argumentation: Understanding student work and designing supportive instructional contexts. *Science Education, 94*(5), 765-793.

Week 14 December 6 Discursive Identity

Brown, Bryan A., John M. Reveles, and Gregory J. Kelly. "Scientific Literacy And Discursive Identity: A Theoretical Framework For Understanding Science Learning". *Science Education* 89.5 (2005): 779-802. Web. 29 Aug. 2016.

Calabrese Barton, A. (2009). Mothering and science literacy: Challenging truth-making and authority through counterstory. In W.M. Roth (Ed.), *Science Education from People for People,* pp. 134-145.

Week 15 December 13 The Public Politics of Science

Jasanoff, S. (1996). Beyond epistemology: Relativism and engagement in the politics of science. *Social studies of science, 26*(2), 393-418.

Kitcher, P. (2010). The climate change debates. *Science, 328*(5983), 1230-1234.

Recommended: Akerson, V. L., Morrison, J. A., & McDuffie, A. R. (2006). One course is not enough: Preservice elementary teachers' retention of improved views of nature of science. *Journal of Research in Science Teaching*, *43*(2), 194-213.

Week 16 December 20 Presentations

*Final Paper due****

Appendix E: Lesson Plan for Large Group Session 1

Time: 100 min. Content: Science as Social Curation, Memory

0-5 Min.	Settle-In/Announcements

5-25 Min.	Mini-Lecture: Memory
	
	1. *What is a memory*
	    a. *The reflection of experiences from the recent or remote past, enabling us to make predictions about the future*
	2. *Taxonomy of memory*
	    a. *There are many types of memories that can be formed, and many brain regions are involved in one or more aspects of memory*
	    b. *Short-term vs. long-term, explicit vs. implicit, declarative vs. procedural, episodic vs. semantic*
	3. *Phases of memory*
	    a. *Three phases of memory: encoding, storage, and retrieval*
	4. *Neural bases of encoding*
	    a. *The hippocampus and parahippocampal cortex involved in encoding information*
	    b. *Subsequent memory paradigm + fMRI*
	    c. *Amnesiacs who suffer global amnesia – Patient HM had the medial temporal lobes removed causing his inability to form declarative memories*
	5. *Neural bases of retrieval*
	    a. *The hippocampus is active in the retrieval of episodic memory*
	6. *Interactions between encoding and retrieval*
	    a. *Retrieval failures happen for a variety of reasons*
	    b. *Transfer-appropriate processing: mood-dependent and state-dependent memory*
	7. *Memory consolidation*
	    a. *Transformation of memories from a labile state to a more stable state*
	    b. *Two forms of consolidation: synaptic and systems consolidation*
	    c. *Amnesiacs – Ribot's Law – degradation of memories in more recent than remote past*
	8. *Standard model of consolidation*
	    a. *We process multiple stimuli at a time, the representations come together in the MTL where the hippocampus binds them, eventually the memory becomes independent of the hippocampus*

	b. This model isn't fully explanatory – there are not always temporal gradients *9. Multiple trace theory of consolidation* *a. Reactivation of the memory trace creates a new MTL ensemble creating multiple traces and sustained dependence on the hippocampus* *10. VAK Learning styles* *a. Visual-audio-kinesthetic learning styles arose from pressure to create a tailored education for students* *b. Self-reported learning styles are often poorly correlated with actual performance* *c. Physical experience enhances science learning* *11. Emotional Memory Enhancements* *a. We are more likely to recall events if they are emotional* *b. There is a benefit for negative memories over positive ones in remembering details of events* *12. Emotional Memory Trade-offs* 1. *Attentional factors – we only attend to what is relevant to us and this attention is necessary for successful memory*
25-55 Min.	Lesson Study: Memory Items [*Appendix G*] *Students will look at the lesson plan given to them and analyze it in an attempt to answer one main question:* *1. In what way is neuroscience presented to students in this lesson?* *2. In what way is the nature of science presented to students in this lesson?* *3. Do these ideas (neuroscience and the nature of science) help one another or inform another as they manifest in the lesson?* *4. What changes/annotations would you make to better incorporate the nature of science into this lesson?* *Students will work in groups, discussing this question. Students will document their ideas and thoughts by completing a lesson analysis of the lesson given as the example.*
55-100 Min.	NOS Discussion: Based on NOS articles assigned for the week (Week 6: Latour & Woolgar, 1979; Longino, 1990) *This section of the lesson is normally led by students of the course and is planned by the students that are leading the week. To maintain normal class engagement protocol, students led this aspect of the study, and designed the NOS discussion that they crafted to facilitate. This was their plan:* *1. Step 1 (3 minutes)*

	a. Answer the following prompt individually: what is the focus of science education? *2. Step 2 (20 minutes)* *a. In groups of 3, discuss your responses. Note differences and come to one consensus* *3. Step 3 (20 minutes)* *Each group presents their consensus definition and the class must agree on one to represent the whole group.*

Appendix F: Lesson Plan for Large Group Session 2

Time: 100 min. Content: Science Laboratory In Context, Attention

0-5 Min.	Settle-In/Announcements
5-15 Min.	Review Focus Group Session 1 Main Points/Questions *The items discussed in each focus group were reviewed along two broad discussion points: the connections between neuroscience and NOS and the use of neuroscience and NOS in curriculum. Points reviewed were as follows:* 1. *How are neuroscience and NOS related?* a. *Neuroscience is a lesser known field that lends itself to modeling the NOS concepts that are important* b. *Competing theories and models in neuroscience become a framework for other research studies, and whichever becomes more prevalent may become the more widely accepted/understood paradigm* c. *Competing theories in balance versus prominent theories/dominant ideas* d. *There is a lot of overlap between neuroscience and other science fields that allow for different lenses (and levels) of observation/inference/understanding* 2. *Implications for curriculum design* a. *Moving away from textbooks and create materials/experiments to deepen learning, critical thinking, associations, etc.* b. *Having students read opposing views based on research studies, allow them to choose which they agree with and argue for that, talk about the NOS practices that play out in the field* c. *Using neuroscience concepts to model NOS practices* d. *Neuroscience is a good model for teaching NOS but it can be challenging to incorporate specifically within curricula...* *The conversation was then opened up to the large group for discussion.*
15-35 Min.	Mini-Lecture: Attention 1. *What is attention?* a. *Selective attention* b. *Top-down vs. bottom-up attention* c. *Covert vs. Overt attention*

	i. Covert attention – the cocktail party effect (E. C. Cherry) *ii. Attention has a limited capacity* *2. Models of Attention* *a. Early Selection Model* *i. Stimuli are selected for further processing or ignored early on, before perceptual analysis is complete* *b. Late Selection Model* *i. All inputs are processed equally by the perceptual system, selection takes place at higher levels of processing* *3. Cueing Tasks – the Posner Paradigm* *a. Reaction times for unexpected stimuli are higher than for expected stimuli* *4. Attentional Control Networks* *a. Dorsal Control Network* *i. Top-down processing and guidance/orientation of attention to spatial information* *ii. Detection of valid cues in Posner's paradigm* *b. Ventral Control Network* *i. Stimulus-driven/bottom-up control* *ii. Detecting unexpected stimuli* *iii. Invalid cues in Posner's paradigm* *5. Emotion Effects on Attention* *a. Fear-relevant stimuli are detected much quicker than fear-irrelevant stimuli, even when given larger search pools*
35-55 Min.	Lesson Study: The Stroop Task [*Appendix H*] *Students will look at the lesson plan given to them and analyze it in an attempt to answer one main question:* *1. In what way is neuroscience presented to students in this lesson?* *2. In what way is the nature of science presented to students in this lesson?* *3. Do these ideas (neuroscience and the nature of science) help one another or inform another as they manifest in the lesson?* *4. What changes/annotations would you make to better incorporate the nature of science into this lesson?* *Students will work in groups, discussing this question. Students will document their ideas and thoughts by completing a lesson analysis of the lesson given as the example.*

55-100 Min.	NOS Discussion: Based on NOS articles assigned for the week (Week 7: Hofstein & Kind, 2012; Kelly et al., 1993)
	
	This section of the lesson is normally led by students of the course, and is planned by the students that are leading the week. To maintain normal class engagement protocol, students led this aspect of the study, and designed the NOS discussion that they crafted to facilitate. This was their plan:
	1. *Think about it: think about the responses to answers on your own, and we will share these out as a group.*
	    a. *What do you view as the importance of laboratory work in science education?*
	    b. *Can there be science education without laboratory work?*
	    c. *Should the laboratory be the central focus of science curriculum or an activity for enrichment?*
	    d. *What role does lab work play in the formation of students' understanding of the nature of science?*
	2. *Group Discussion: Answer the question assigned to your table group on a large piece of chart paper. Feel free to use pictures in your answer.*
	    a. *<u>Group 1:</u> According to Hofstein & Kind (2012) "using appropriate technologies in the school laboratory can enhance learning of important scientific ideas". How has technology made laboratory activities more accessible to different content areas and altered the role of the laboratory activity in science education? Give at least one example to illustrate your point.*
	    b. *<u>Group 2:</u> Give an example of a "typical lab". Is it a "cookbook" lab, or an inquiry-based lab? How can you make the lab more inquiry based?*
	    c. *<u>Group 3:</u> What is the role of the educator in a "cookbook" lab situation vs. a more constructivist, inquiry-based lab activity? Give at least one example to illustrate your point.*

Appendix G: Lesson Plan for Large Group Session 3

Time: 100 min. Content: Multicultural Science, Emotion Regulation

0-5 Min.	Settle-In/Announcements
5-15 Min.	Review Focus Group Session 2 Main Points/Questions *This section includes a small review led of what was discussed in the first catalytic group session. The conversation topics included:* *1. What were the main points that you discussed in your small group session? (i.e., what connections did you make between neuroscience and NOS, if any? How did it relate to the lesson study, or the lesson plans that you normally have to write?)* *a. Have each group briefly summarize the items they wrote down on the Focus Group Facilitation Guide, with prompts from the researcher as necessary.* *b. After each group has shared their main points, ask the larger group to question and/or comment on each group's statements* *2. What questions do you still have about being able to connect NOS and neuroscience?* *Have each group respond as necessary, and then open up the discussion to all participants.*
15-35 Min.	Mini-Lecture: Emotion Regulation *1. What is emotion?* *a. Emotion is an identifiable feeling state involving physiological arousal, a cognitive appraisal of the situation or stimulus causing that internal body state, and an outward behavior expressing the state* *2. How do we generate emotions?* *a. There are at least 4 theories on how emotions occur* *3. James-Lange Theory* *a. Suggests that emotional feelings result when an individual becomes aware of a physiological response to an emotion-provoking experience* *4. Cannon-Bard Theory* *a. emotion-provoking stimulus is transmitted simultaneously to the cerebral cortex, which is responsible for conscious experience of the emotion, and to the sympathetic nervous system, which causes physiological arousal* *5. Schachter-Singer Theory* *a. two things must happen for a person to feel an emotion:* *i. There must be physiological arousal*

	ii. There must be a cognitive interpretation of the arousal, so the person can label it as a specific emotion *b. High-Bridge Study – men were more love-struck on the bridge than in a non-anxious environment* *6. Lazarus Theory* *a. Proposes that a cognitive appraisal is the first step in an emotional response and that all other aspects of an emotion, including physiological arousal depend on it* *7. Constructivist Theory* *a. Emotions are human-made concepts that emerge as we make meaning out of sensory input from the body and from the world* *8. Emotion and the brain* *a. Emotional processing depends on the amygdala, housed in the limbic system – necessary for determining what we call salient or significant* *9. Emotion regulation* *a. There are many ways to change what emotions we experience, how intensely we experience them, and in what situations we experience them* *b. Most successful emotion regulation mechanism is cognitive reappraisal - Changing the way we think about an emotional situation so as to change its emotional impact* *10. Cognitive reappraisal* *a. Increasing and decreasing emotional intensity is associated with activity in the prefrontal cortex – lateral and medial as well as ACC* *11. What happens when regulation goes awry?* *a. Social isolation, poor academic performance in children, poor work performance in adults, risky behaviors – drug and alcohol use, self-hard, psychopathologies, low SES and chronic stress affect ER* *12. Academic Performance and ER* *a. Emotion regulation as predicted by parents positively predicted academic success/productivity in the classroom setting as well as on both math and early literacy standardized tests* *13. Criminal psychopaths* *a. Psychopaths show reduced activity regions including the hippocampus and amygdala but increased activity in the regions of the lateral PFC*
35-55 Min.	Lesson Study: Your Incredible Memory [*Appendix I*]

	Students will look at the lesson plan given to them and analyze it in an attempt to answer one main question: *1. In what way is neuroscience presented to students in this lesson?* *2. In what way is the nature of science presented to students in this lesson?* *3. Do these ideas (neuroscience and the nature of science) help one another or inform another as they manifest in the lesson?* *4. What changes/annotations would you make to better incorporate the nature of science into this lesson?* *Students will work in groups, discussing this question. Students will document their ideas and thoughts by completing a lesson analysis of the lesson given as the example.*
55-100 Min.	NOS Discussion: Based on NOS articles assigned for the week (Week 9: Cobern & Loving, 2001; Brickhouse, 2001; Calabrese Barton, 1997) *This section of the lesson is normally led by students of the course, and is planned by the students that are leading the week. To maintain normal class engagement protocol, students led this aspect of the study, and designed the NOS discussion that they crafted to facilitate. This was their plan:* *1. Rumors Activity* *a. Have students rank the following statement on a 1 to 5 scale (1 = strongly disagree, 5 = strongly agree).* *i. Scientific knowledge is based on or influenced by our personal feelings, tastes, or opinions.* *b. Write this ranking on a post-it note.* *c. Students will share their response to the statement with the person next to them. Then, exchange post-it's. Have students get up and repeat this 3 more times with other students in the room.* *d. Discussion: Have your thoughts on scientific knowledge changed after this activity? Does this activity represent the emergence of real, scientific knowledge? Is science a subjective enterprise? How does scientific knowledge emerge?* *2. Open-forum questions* *a. Is science personal, or objective? Do they influence each other? (personal experience & objective truth)* *b. How may students' personal beliefs and emotions color or idealize science?* *c. How may students' beliefs make teaching science difficult?*

	d. Has learning in Nature and Practice of Science been 'static' or 'dynamic' for you? *e. How may awareness of student beliefs help drive instruction?* *f. How should teachers direct students regarding what counts as "scientific knowledge"?*

Appendix H: Lesson Plan for Lesson Study in Large Group Session 1

Memory Items. Grade Level 4 – 12. Lesson length 1 Class Period.

Lesson Summary:
Do you remember an item better if you discussed it or held it in your hand as opposed to simply seeing it? Students learn about memory capacity and different ways to remember things.

Standards Alignment:

Next Generation Science Standards
- 3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
- 4-LS1-1. Construct an argument that plants and animals have internal and external structures that function to support survival, growth, behavior, and reproduction.
- 4-LS1-2. Use a model to describe that animals receive different types of information through their senses, process the information in their brain, and respond to the information in different ways.
- MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.
- MS-LS1-3. Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.
- MS-LS1-8. Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories.
- Framework for K-12 Science Education: Science & Engineering Practices 1,3,5,6,8

Objectives – Students Will:

- Experience different ways of remembering items
- Discuss different methods of remembering
- Know several regions of the brain that mediate declarative type of memory

Assessment Options:

- Graph the results and discuss what the results show
- Engage students in discussion about remembering information
- Design other experiments that investigate different ways of remembering

Materials:

- 2-3 large trays -- cafeteria trays work well.
- 2-3 sets of 10-20 small items -- e.g. comb, eraser, toy car, cork, etc.
- sheet/towel to cover the items on the tray
- paper and pencil to write down what is remembered -- a science or lab notebook can be also be used.
- timer (optional)

Note: additional trays and sets of items for each group of students are needed if students will do the "touch and talk" part of this activity.

Procedures:

Engage:

1. *Preparation*: arrange items on the tray. Cover with a sheet or towel.
2. Tell students that
    - there are items underneath the sheet or towel.
    - they are to look at the items but cannot touch or talk about the items.
3. After one minute - you can use a timer to be accurate - cover the tray and ask the students to write down as many items as they can remember.

Explore:

1. Ask the students what additional methods they could use to remember more items.
2. Tell students that the class will try the activity again using a different way to remember items.

Touch-and-Talk Activity

1. Place the additional trays in different parts of the room.
2. Divide students into 2-3 groups (depending on the number of trays available) and ask the groups to go to their respective trays.
3. Inform students that you will show them the items and this time they can touch and talk about the items.
4. Go to each tray and give the students at least 1 minute to touch and talk about the items.
5. After all the students have finished the activity, ask them to write down the items they remembered.

Explain:

- (Optional) Plot the results from the first and second activity. Plot the number of items remembered, the number of students who remembered each item, etc. Discuss the results with the students. Look for patterns and see if the class can come up with explanations for the patterns.
- Discuss the anatomy and function of the *hippocampus* and the *cerebral cortex*. If the class did sheep brain dissection, link this activity to their knowledge about the hippocampus.
- Talk about different ways that people remember.

1. One way is by forming *mnemonic* devices. An example of this is HOMES for the first letter of the names of the five great lakes.
   H- Huron
   O- Ontario
   M – Michigan
   E – Erie
   S – Superior
2. Another way to remember is by forming associations. Associations involve forming mental connections between senses, ideas, memories, and physical movements.
3. Students can also clump items that may be similar.

- Ask students if they used a specific strategy for remembering the items. Students can refer to the graph to see if items remembered were clumped in a certain way.

Elaborate and Evaluate:

- Direct students to work in groups and ask them to develop their own memory activity. They can either write about their proposed experiment or perform their own experiment.

Appendix I: Lesson Plan for Lesson Study in Large Group Session 2

The Stroop Task. Grade Level 8 - 12. Lesson length 1 Class Period.

Lesson Summary:
The Stroop Effect was first described in a 1935 article by American Psychologist John Ridley Stroop who developed this task. At this station, students read three lists of color words - a congruent, an incongruent, and a control list - and ask their peers to identify which of the lists was more challenging and why.

Standards Alignment:

Next Generation Science Standards

- MS-LS1-3. Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.
- MS-LS1-8. Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories.
- HS-LS1-2. Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms, e.g. organism movement in response to neural stimuli.
- HS-LS1-3. Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.
- Framework for K-12 Science Education: Science and Engineering Practices 1, 2, 3, 8

Objectives – Students Will:

- Predict how quickly they can read a given list of words
- Perform an experiment to establish relationships between naming a color and automatically reading a presented word

Assessment Options:

- Explain how selective attention plays a role in how quickly we see words/colors
- Create an experiment that utilized automatization to overpower the Stroop effect

Materials for each group (2 people):

- 6 timing devices
- 3 lists of words (congruent, incongruent, control)
- 1 data sheet per group

Procedures:

Engage:

1. *Preparation: set a timer to 1:00 on the board for all students to see*
2. Ask students to stand up out of their seats. They are going to attempt to do two things at once. One half of the class is going to march in place and count backwards from 100, the other half of the class is going to attempt to rub their stomachs and pat their heads. The students will attempt to do these tasks for 1 minute. After 1 minute, have them switch and try the other activity (i.e. if they marched in place and counted for the first minute, they will rub their stomachs and pat their heads for the second minute).
3. Ask students these probing questions after they complete both activities:
    a. Why was it hard to do one set of activities over the other?
    b. Did it get easier over time to attempt to do both things at once?

Explore:

1. Have one group member be in charge of timing the current group member being tested while the other member presents the current word list to the current subject.
2. Notify the member being tested that his/her task is to name the color that the words are written in as quickly as possible without making any mistakes.
3. Present the subject with one of the lists and immediately begin timing.
4. Record the time in seconds when they say the word (i.e. at 4 seconds, 8 seconds, etc.) and note whether any mistakes in naming were made (i.e. if they say the wrong word or the color). All data should be recorded in the table below.

Word #	Time (sec) Same Word / Color	Time (sec) Different Word / Color	Time (sec) Control
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

5. Continue in the same way with all other word lists and across other subjects. Make sure that word lists have been presented in the correct orientation (right side up) to all group members.
6. Ask students to graph the data and compare the trends for each list.

Explain:

1. Begin by asking students what trends they noticed in the data.
    a. Why did it take longer to read the words of a different color than it did to read the words of the same color?
    b. Did it take more focus/effort to read words of a different color?
    c. Did you get better at reading the words as time went on?
2. Have students read an about the Stroop effect (below):

When you first learned to tie shoe laces, you needed to carefully think through each step of the process. Now, you probably do not even seem to think about the steps, but simply initiate a series of movements that seem to proceed without any further influence. When a behavior or skill seems to no longer require direct interaction, neuroscientists say it is *automatized*.

Many behaviors can become automatized: typing, reading, writing, bicycling, piano playing, driving, etc. Automatization is interesting because it is an important part of daily life. We perform a variety of automatized behaviors quickly and effortlessly. In some cases people report that they do not consciously know *how* the behavior is performed, they just will it to happen, and it does happen.

To explore properties of automatized behaviors, neuroscientists and cognitive psychologists often put observers in a situation where an automatized response is in conflict with the desired behavior. This allows researchers to test the behind-the-scenes properties of automatized behaviors by noting their influence on more easily measured behaviors. This demonstration explores a well-known example of this type of influence, the Stroop effect.

Stroop (1935) noted that observers were slower to properly identify the color of ink when the ink was used to produce color names different from the ink. That is, observers were slower to identify red ink when it spelled the word *blue*. This is an interesting finding because observers are told to not pay any attention to the word names and simply report the color of the ink. However, this seems to be a nearly impossible task, as the name of the word seems to interfere with the observer's ability to report the color of the ink.

A common explanation for the Stroop effect is that observers (especially college undergraduates) have automatized the process of reading. Thus, the color names of the words are always processed very quickly, regardless of the color of the ink. On the other hand, identifying colors is not a task that observers have to report on very often, and because it is not automatized it is slower. The fast and automatic processing of the color name of the word interferes with the reporting of the ink color.

The Stroop task, and its many variations, are a commonly used tool in cognitive psychology to explore how different types of behaviors interact. This demonstration allows you to participate in a simple version of the Stroop task.

The actual words have a strong influence over your ability to say the color of the words. The interference between the different information (what the words say and the color of the words) your brain receives causes a problem. One theory that may explain the Stroop effect is Selective Attention Theory. This theory posits that the interference occurs because naming colors requires more attention than reading words.

3. Explain to students the Selective Attention Theory and the three attentional networks (Dorsal, Ventral, and Subcortical)
4. Discuss with students the roles of these different attentional networks on what we see and how quickly we orient ourselves to objects in the visual field
5. Discuss the role of priming on automaticity.

Elaborate/Extend:

1. Have students think about the ways the concept behind the Stroop task apply to their daily lives.
    a. In what other ways have we used automatization to help us in life?
    b. How do we (as humans) benefit from being able to select what we pay attention to?
    c. How do we become desensitized to certain stimuli in our environment such that we stop paying critical attention to it?
    d. What is the evolutionary benefit of selective attention?

Materials Reference:
These lists of words should be printed onto index cards or cardstock.

CONTROL	CONGRUENT	INCONGRUENT
DOG	YELLOW	BLUE
BOAT	BLUE	YELLOW
CHAIR	RED	BLUE
WINDOW	GREEN	RED
FAN	RED	YELLOW
FART	GREEN	GREEN
KIDS	YELLOW	RED
TRAY	BLUE	YELLOW
BOTTLE	RED	GREEN
FENCE	YELLOW	RED
TOY	GREEN	BLUE
SPORT	BLUE	GREEN

Appendix J: Lesson Plan for Lesson Study in Large Group Session 3

Mirroring Emotions. Grade Level 9 – 12. Lesson length 1 class period.

Lesson Summary:
The ability to identify with and understand another person's situation, feelings, or motives is called empathy. Recent developments in neuroscience have focused on a system within the brain called 'mirror neurons" as a likely explanation for emotional empathy. In this lesson students explore emotions and the behavioral aspects of empathy through mirroring the emotions of other students while watching emotionally evocative videos.

Standards Alignment:

Next Generation Science Standards

- 1-LS1-1. Use materials to design a solution to a human problem by mimicking how plants and/or animals use their external parts to help them survive, grow, and meet their needs.
- MS-LS1-3. Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.
- MS-LS1-8. Gather and synthesize information that sensory receptors respond to stimuli by sending messages to the brain for immediate behavior or storage as memories.
- HS-LS1-2. Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms, e.g. organism movement in response to neural stimuli.
- HS-LS1-3. Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.
- 3-LS3-2. Use evidence to support the explanation that traits can be influenced by the environment.
- 3-LS4-2. Use evidence to construct an explanation for how the variations in characteristics among individuals of the same species may provide advantages in surviving, finding mates, and reproducing.
- HS-LS2-8. Evaluate the evidence for the role of group behavior on individual and species' chances to survive and reproduce.
- Framework for K-12 Science Education: Science and Engineering Practices 1, 2, 3, 8

Objectives – Students Will:

- Describe importance of emotions and mirror neurons on social survival and homeostasis.
- Carry out an inquiry-based experiment on the evoked emotional responses and the perception of those responses.
- Build observational skills for recognizing accurate emotional states in social situations.

Assessment Options:

- Explain how the neural information regarding emotion flows to and from the brain.
- Explain how the emotions influence muscle movement of the face.
- Explain why accurate reading of another person's emotions builds social cohesion and promotes evolutionary fitness.
- Explain the scientific understanding of brain function behind the TV show "Lie to Me." How is Dr. Cal Lightman (the main character) able to crack each case? How might you use some of these techniques in your life?

Terms – important vocabulary that can strengthen the lesson – select items according to the needs and abilities of your students.

- Amygdala – part of the brain involved in processing the memory of emotional reactions, notably fear and anger
- Autonomic nervous system – part of the peripheral nervous system; regulates heart rate, breathing, perspiration; also called the involuntary nervous system
- Brain stem – the part of the central nervous system connecting the brain to the spinal cord. It contains pathways sending information to and receiving information from the spinal cord and peripheral nerves.
- Fronto-parietal cortex – region of the brain involving the frontal and parietal lobes, controls spatial attention
- Homeostasis – self-regulating process by which a system remains stable by adjusting to changing conditions
- Hypothalamus – part of the brain that processes appetite, thirst, hormone regulation, control of internal body functions, sexual functions, and diurnal rhythms; located below the thalamus
- Limbic system – part of the brain that processes the sense of smell, long-term memory, and emotion; made up of several structures including the amygdala and hippocampus; also known as the "emotional system"
- Mirror neurons – neurons that fire when an individual does an action or sees the same action done by another individual, thereby, "mirroring" the behavior
- Prefrontal cortex (PFC) – the very most anterior (rostral) part of the cortex which controls planning and thought

Materials:

- Lab notebook/science journal for each student (optional)
- Nova ScienceNOW video excerpt (4:35 in length) - "Mirror Neurons Engagement Video"
- Seven evoking videos:
  Video 1: happy ukulele boy - www.youtube.com/watch?v=ErMWX--UJZ4
  Video 2: happy baby laughing at mom - www.youtube.com/watch?v=-wIEihDAcpU
  Video 3: surprising basketball blooper - www.youtube.com/watch?v=kHz8-1UFaKQ
  Video 4: scary snake - http://www.youtube.com/watch?v=IogEiKhEJFo
  Video 5: disgusting beetle eating -
  www.youtube.com/watch?v=Uj9CysSSsps&NR=1

Video 6: sad commercial -
www.youtube.com/watch?v=dpf2hsZGsJM&feature=related
Video 7: scary commercial - www.youtube.com/watch?v=Y4Zn9LR5D1M

- Technology to show "Mirror Neurons Engagement Video" and then evoking videos 1 thru 7.
    - One student-accessible computer or mobile device (mp3, iTouch, etc.) per 3-5 member student group with the appropriate media files on them.
    - A media projector and accessible computer loaded with these videos for viewing videos simultaneously as a whole class.
- Ear-phone attachments, so viewer hears video feed but others in the group cannot.

Procedures:

Engage:

- To begin the activity, show students pictures of faces (Facial Expression Pix) displaying the basic emotions. Ask students to identify the emotion and explain what clues led them to that conclusion. Restate student thoughts to begin to build a vocabulary for talking about emotions.

  Discuss with students how they are able to recognize emotional responses and why these are important. Ask students to list all of the emotional states they can.

  Narrow down the list to 4-8 primary emotions, each corresponding to a facial expression like the ones used by the scientist in the engagement video. Describe the facial expressions associated with each emotion. Be as detailed as possible in the descriptions, e.g. corners of mouth pulled down, eyes wide open, eyebrows raised, etc.

Explore:

- Assemble the class into groups of three. A two-student group will consist of only a viewer and a primary observer as explained below.
- One student from each group will sit down so s/he can fully see the video. These students are the *viewers*. The other students will split into two groups: *primary observers* and *secondary observers*.
- Primary observers watch the viewer from their group in such a way that they can fully see the viewer's face but not see the projection screen. These observers will document the changes in the viewer's facial expression and label what they see with one of the emotions listed during the Engage section above.
- Secondary observers watch the primary observers in such a way that they can fully see the primary observers' faces but not the computer screen or the primary viewer's face. These observers will document the changes in the primary observer's facial expression and label what they see with one of the emotions listed during the Engage section.

Explain:

- Discuss with students what they thought about their results. Ask them to compare and contrast their results and draw conclusions.
    - Was there a difference between the number of words remembered during round 1 versus round 2?
    - Were there specific words that they remembered vividly?
    - Did the order of the words affect their ability to be recalled?
    - Were words recalled that were not in the list?
- Discuss the anatomy, location, and function of the cerebral cortex and the hippocampus.

Explore Results:

After all the data are collected, direct the small groups to discuss their individual results. Then bring the class back together to discuss results as a group.
Discuss what the data shows.

- Are there any patterns in the data of the emotions being expressed? Why would these occur? Why did emotions expressed by the primary observer mimic those expressed by the viewer even though the primary observer did not look at the screen? Why would such a behavior be beneficial?
- Are there similarities in the emotions expressed in response to any one video? Can some of the listed emotions be combined into a single category?

Extension:

1. Try this experiment with the primary viewers holding a pencil in their teeth. What happens to their ability to express emotions? Why do you think this happens?
2. Brainstorm with your group and briefly describe an experiment that could test this phenomenon more accurately. Make a list of things you need to consider before testing. Try to be as complete as possible. *Hint: How could you use a camera or a fun house mirror? How does your experiment test brain function?*

Elaborate/Evaluate:

1. Show the "Mirror Neurons Engagement Video" (length 4:35) – an excerpt of the Nova ScienceNOW segment "Mirror Neurons" which is 14 minutes long.
2. The video could be shown to the group by using a media projector or, if conducting the lesson in a media lab, your students could watch the video at their workstations. Ask "How does this information change your interpretations of the data?"

<u>Background Materials:</u>

1. What are mirror neurons?
    a. Mirror neurons form a circuit of neurons in the *fronto-parietal cortex* that become active both when one observes behaviors in others and when one performs that behavior oneself. In human brains, mirror neurons are thought to help explain many behaviors including learning language, imitating movement, and experiencing empathy. The ability to respond to others'

intentions and emotional states may also be a function of the *mirror neuron system*.

   b. The current understanding of mirror neurons is that when an individual perceives an emotion of another person, a small number of mirror neurons begin to fire that would be activated if that individual was actually experiencing the emotion. Thus one can perceive the experiences of others by watching them.
   c. A great resource for understanding mirror neurons and how they relate to this experiment is the PBS ScienceNOW video which is designed for classroom viewing; the web site contains an explanatory essay. www.pbslearningmedia.org/resource/hew06.sci.life.reg.mirrorneurons/mirror-neurons/

2. How does your brain recognize and interpret emotions?
   a. All sensory information from one's sensory and internal organs enters the brain at different locations but is transmitted and processed for emotional content by two interlinked systems: the *limbic system* and the *prefrontal cortex*.
   b. The key structure in the limbic system, the *amygdala*, first receives information from the body and the senses and then quickly processes it for emotional content. The outputs of the amygdala can trigger quick motor reactions in facial muscles to form the facial expressions we interpret as emotional responses. It can also trigger full body motor responses such as flight, fight, tend, or defend.
   c. The outputs of the amygdala control the automatic bodily responses that are involved in emotions by affecting the homeostatic control center of the *hypothalamus*, which in turn controls the hormonal secretions and the sympathetic nerves of the body. The quick activation of the sympathetic nerves that innervate the internal organs gives a person the raw feelings like catching his/her breath when being surprised or his/her heart racing when fearful. All this happens without taking the additional time to engage the rational decision-making parts of the cortex first.
   d. Information is also processed and interpreted in a longer route that ends in the prefrontal cortex. The prefrontal cortex is involved in the final phase of emotional processing. After the initial automatic, emotional reaction, humans engage the rational observation- and decision-making area of the cortex to choose how best to react. Additional synapses and time are required for a person to cognitively recognize an emotion. Hence, saying "I feel sad" happens only after the introspection and examination of one's thoughts and feelings, such as tightness in the chest or "that sinking feeling."
3. How do emotions control facial expressions?
   a. The muscles of facial expression are controlled by a pair of nerves that originate in the *brain stem*. The neurons that control the facial muscles receive input from both the motor area of the cortex and the areas of the brain involved in emotional processing.
   b. The emotional input from the limbic areas and *autonomic nervous system* are the cause of fast and involuntary facial movements in response to emotional

stimuli. Cortical input produces voluntary facial movements generating the facial expression that we show to the world. Cortical input can also suppress involuntary expressions.

   c. For an in-depth review of this system, please see emedicine.medscape.com/article/835286-overview

4. How does what we learn in this experiment apply to real life? What is the relationship between social interactions and homeostasis?
   a. Facial expressions are an important channel of nonverbal communication. While many animal species display facial expressions, they are particularly evident in primates and, especially, in humans. Facial expressions convey subtle emotional messages in person-to-person communication. Accurate interpretation of the message being communicated prevents unnecessary conflict, establishes social hierarchies, and facilitates bonding within a group.
   b. Recognition of and appropriate response to these non-verbal expressions of emotion aid survival within the society. Emotionally directed communication and cooperation provide the feedback signals for homeostatic control of social organization. *Homeostasis* ensures continuation of the organism's life and perpetuation of the social group.
   c. Correct recognition and response to non-verbal cues rely on mirror neurons. Mirror neurons may help us to understand a person's actions and to learn new skills by imitation. Some researchers speculate that disruptions in the mirror neuron system may underlie some cognitive disorders, particularly autism.

Appendix K: Lesson Plan for Large Group Session 4

Time: 100 min. Content: NGSS/Science Literacy, Intervention Summary

0-5 Min.	Settle-In/Announcements
5-15 Min.	Review and Summarize Neuroscience Topics and NOS discussions 1. *Neuroscience Topics* a. *Memory* b. *Attention* c. *Emotion Regulation* 2. *NOS discussions* a. *Kuhn's Science Revolutions and Paradigms* b. *Science as social curation* c. *Science laboratory in context* d. *Science epistemologies* e. *NGSS and Science Literacy*
20-45 Min.	Standards Applications: Applying Neuroscience and NOS to the NGSS and Curriculum Design 1. *Taking into account everything we have discussed so far (neuroscience and NOS), your task is to create either a unit plan, a lesson plan, or a curriculum map that considers (or possibly does not) these aspects of neuroscience and NOS. You are also tasked with using the NGSS to frame your plan.* 2. *You will have 30 minutes to design your lesson/unit/curriculum map.* 3. *Please draw your design on chart paper, as we will share out these designs with the whole class.*
45-100 Min.	NOS Discussion: Based on NOS articles assigned for the week (Week 10: Lee, 1997; NRC, 2011) *This section of the lesson is normally led by students of the course and is planned by the students that are leading the week. To maintain normal class engagement protocol, students led this aspect of the study, and designed the NOS discussion that they crafted to facilitate. This was their plan:* 1. *NGSS Review/Mini-Lecture* a. *What is the NGSS* b. *Principles of the Framework*

	c. Instructional Shifts *2. Activity I: Understanding how scientists work* *a. What are the implications for teaching the scientific method?* *b. As a team, create a visual representation of the scientific method based on the Framework. What should a scientific method poster look like now?* *3. Activity II: Scientific literacy in the era of NGSS* *a. What NGSS' expectation of being scientifically literate?* *b. As a team, add to the poster about changes of scientific literacy in the context of NGSS. What should the scientifically and technologically literate person know, value and be able to do--as a citizen?*

Appendix L: Mid-Intervention Reflection Prompts

Mid-Intervention Reflection Prompt

---

1. Do the ideas in the readings we have had so far for this class fit our discussions of the nature of science (NOS)? How have your ideas about NOS changed over the course of this intervention? *In your discussion, try to focus on the elements of tentativeness, creativity, observation vs. inference, subjectivity, and relationships of theory and law.*

2. In what ways have your experiences in this intervention *(the neuroscience lectures, the lesson study, the NOS activities, and the focus group if you are in one)* impacted the attitudes that you may carry towards using neuroscience and/or NOS to inform science teaching and learning?

Appendix M: Small Group Session Discussion Facilitation Guide

Note: These sessions are discussion based, meaning that by the end of the session, you will have broadly discussed the two questions below. Please indicate your discussion points for each question on the sheet, including other questions that arose during the discussion. On the final page, you will create a collaborative set of final points and discussion questions that you would like to share with the entire class during the next class meeting. You will be instructed to spend about 25 minutes on questions 1 and 2, respectively, and 10 minutes on question 3.

1. Are there any connections that can be made between the neuroscience topic that was discussed in the class meeting (Session 1: Memory, or Session 2: Attention) with the nature of science as we have learned thus far in the course?

2. How can ideas of the nature of science gained in prior sessions of the course can be integrated with neuroscience in education as curriculum topics (i.e. the lesson plans that we used for lesson study and the lesson plans that you wrote prior to the first neuroscience class session)?

3. What were the main points of your focus-group discussion (questions 1 and 2) that you would like to bring back to the next class meeting? What questions do you have that you would like to propose to the class during the next class meeting?

Appendix N: Student Understanding of Science and Scientific Inquiry Questionnaire

Please read EACH statement carefully, and then indicate the degree to which you agree or disagree with EACH statement by circling the appropriate letters to the right of each statement (SD= Strongly Disagree; D = Disagree More Than Agree; U = Uncertain or Not Sure; A = Agree More Than Disagree; SA = Strongly Agree).

1. Observations and Inferences
    a. Scientists' observations of the same event may be different because the scientists' prior knowledge may affect their observations.
       SD D U A SA
    b. Scientists' observations of the same event will be the same because scientists are objective.
       SD D U A SA
    c. Scientists' observations of the same event will be the same because observations are facts.
       SD D U A SA
    d. Scientists may make different interpretations based on the same observations.
       SD D U A SA

With Examples, explain why you think scientists' observations and interpretations are the same or different.

2. Change of Scientific Theories
    a. Scientific theories are subject to on-going testing and revision.
       SD D U A SA
    b. Scientific theories may be completely replaced by new theories in light of new evidence.
       SD D U A SA
    c. Scientific theories may be changed because scientists reinterpret existing observations.
       SD D U A SA
    d. Scientific theories based on accurate experimentation will not be changed.
       SD D U A SA

With examples, explain why you think scientific theories change or do not change over time.

3. Scientific Laws vs. Theories

a. Scientific theories exist in the natural world and are uncovered through scientific investigations.
   SD D U A SA
b. Unlike theories, scientific laws are not subject to change.
   SD D U A SA
c. Scientific laws are theories that have been proven.
   SD D U A SA
d. Scientific theories explain scientific laws.
   SD D U A SA

With examples, explain the difference between scientific theories and laws.

4. Social and Cultural Influence on Science
   a. Scientific research is not influenced by society and culture because scientists are trained to conduct "pure", unbiased studies.
      SD D U A SA
   b. Cultural values and expectations determine what science is conducted and accepted.
      SD D U A SA
   c. Cultural values and expectations determine how science is conducted and accepted.
      SD D U A SA
   d. All cultures conduct scientific research the same way because science is universal and independent of society and culture.
      SD D U A SA

With examples, explain how society and culture affect or do not affect scientific research.

5. Imagination and Creativity in Scientific Investigations
   a. Scientists use their imagination and creativity when they collect data.
      SD D U A SA
   b. Scientists use their imagination and creativity when they analyze and interpret data.
      SD D U A SA
   c. Scientists do not use their imagination and creativity because these conflict with their logical reasoning.
      SD D U A SA
   d. Scientists do not use their imagination and creativity because these can interfere with objectivity.
      SD D U A SA

With examples, explain why scientists use or do not use imagination and creativity.

6. Methodology of Scientific Investigation
   a. Scientists use different types of methods to conduct scientific investigations.
      SD D U A SA
   b. Scientists follow the same step-by-step scientific method.
      SD D U A SA
   c. When scientists use the scientific method correctly, their results are true and accurate.
      SD D U A SA
   d. Experiments are not the only means used in the development of scientific knowledge.
      SD D U A SA

With examples, explain why scientists follow a single, universal scientific method or use different methods.

Appendix O: Attitudes and Beliefs about NOS-Neuroscience Connections Survey

Pre-Survey: Attitudes and Beliefs about NOS-Neuroscience Connections

1. Using examples from neuroscience research can be a good context for understanding the nature of science (NOS).

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

2. It may be easier to make connections between NOS and neuroscience if a teacher knows more about the neuroscientific domain.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

3. Neuroscience and NOS are disparate scientific endeavors and bear few obvious connections to one another.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

4. I am interested in the integration of NOS and neuroscience to better understand NOS concepts.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

5. I believe that it is necessary to learn NOS to be an effective science educator.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

6. It is possible to explain NOS concepts using evidence from the neurosciences as scientific examples.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

7. There is a meaningful and logical relationship between neuroscience and NOS.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

8. The many qualities of NOS are an excellent resource that should be used to better understand how scientific knowledge is developed and evolves over time.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

9. I believe that it is valuable to learn the various historical and philosophical aspects of NOS.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

10. Applying NOS principles to a science discipline that we teach is useful for developing a holistic understanding of NOS.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

11. I find learning about NOS to be a rewarding experience.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

12. In my opinion, learning about NOS can enhance my understanding of a science domain.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

<u>Post-Survey: Attitudes and Beliefs about NOS-Neuroscience Connections</u>

1. Using examples from neuroscience research can be a good context for understanding the nature of science (NOS).

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

2. It may be easier to make connections between NOS and neuroscience if a teacher knows more about the neuroscientific domain.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

3. Neuroscience and NOS are disparate scientific endeavors and bear few obvious connections to one another.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

4. I am interested in the integration of NOS and neuroscience to better understand NOS concepts.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

5. I believe that it is necessary to learn NOS to be an effective science educator.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

6. It is possible to explain NOS concepts using evidence from the neurosciences as scientific examples.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

7. There is a meaningful and logical relationship between neuroscience and NOS.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

8. The many qualities of NOS are an excellent resource that should be used to better understand how scientific knowledge is developed and evolves over time.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

9. I believe that it is valuable to learn the various historical and philosophical aspects of NOS.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

10. Applying NOS principles to a science discipline that we teach is useful for developing a holistic understanding of NOS.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

11. I find learning about NOS to be a rewarding experience.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

12. In my opinion, learning about NOS can enhance my understanding of a science domain.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

13. I feel more confident in including neuroscience and NOS in my teaching.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

14. By participating in this part of the course, I found it useful to think about integrating neuroscience ideas with NOS as a way of clarifying the meaning of NOS.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

15. I believe that students would be positively attracted to learning science when neuroscience and NOS are integrated, based on what I learned so far.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

16. Many features of NOS can be identified and exemplified in neuroscience.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

17. I would recommend that someone attempting to learn NOS could use some aspects of neuroscience to increase their understandings.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

18. As a result of this course, neuroscience has helped me to see NOS from a different perspective.

Strongly disagree	Disagree	Neutral/Not Sure	Agree	Strongly agree
[1]	[2]	[3]	[4]	[5]

Appendix P: Demographic Survey

1. What is your age?
    a. 15-20
    b. 21-25
    c. 26-30
    d. 31-35
    e. 36-40
    f. 41-45
    g. 46-50
    h. 51-55
    i. 56-60
    j. 61-65
    k. 65+
2. What is your gender?
    a. Male
    b. Female
    c. I choose to not identify.
3. What race/ethnicity do you identify with? Please, try to circle only one response.
    a. Caucasian/White
    b. African/African-American/Black
    c. Latin/Latin-American
    d. Asian/Asian-American/Pacific Islander
    e. Other: ____________________

4. What type of bachelor's degree did you obtain? If you obtained a degree in a science/applied science, please be as specific as possible (i.e. Mechanical Engineering, or Biology with a concentration in Marine Science).

5. Do you have any degrees higher than a bachelor's degree? If so, please list and describe your degree below (i.e. PhD in Chemistry, M.A. in Philosophy).

6. What program are you enrolled in at Teachers College? (i.e. M.Ed. in Science Education, M.A. in Psychology and Education)

7. What is the reason that you are enrolled in this course?

8. What are you looking to do with your degree once you graduate from Teachers College?

Appendix Q: Observation Protocol for Large Group Session

Category	Conceptual Definition	Operational Definitions/Items
Content Integration (CI)	Content integration is an expression where the student takes two seemingly disparate ideas and connects them together based on underlying principles of similarity.	• Defined their understanding of NOS using neuroscience • Described their understanding of NOS using neuroscience • Evaluated neuroscience research based on their understanding of NOS • Compared/contrasted the reliability of neuroscientific findings using NOS as a framework
Discussion Quality (DQ)	Discussion quality refers to the distinctive characteristics of the verbal interactions between students. Discussion quality is categorized as factual, conceptual, analytical, or evaluative, according to Bloom's taxonomy.	• Made brief statements about facts related to neuroscience and NOS (F) • Discussed higher than factual ideas about neuroscience and NOS (C) • Analyzed ideas about neuroscience and NOS by looking at the whole in terms of its constituent parts and their relationships (A) • Made statements about neuroscience and NOS that were related to judgement (E)

Social Interactions (SI)	Social interactions refer to the verbal and non-verbal methods of communication that students use to communicate with one another. In this case, social interactions refer to the actions of students labeled as 'small group' or 'large group', and how these actions are separated or integrated within these two groups.	• Engaged in discussion only with 'small group' (S) members
		  o Catalyst/focus group
		• Engaged in discussion only with 'large group' (L) members
		  o Everyone minus the small group members
		• Both 'small group' and 'large group' members interacted with each other in their discussions - integrated (I)

Ambiance (AM)	Ambiance is the mood, character, tone, or atmosphere of the classroom, and is based on emotional aspects of the students in that classroom.	• Positive and supportive interactions between students (P) o Highlighted strong aspects of other students' statements o Critically evaluated other students' statements while acknowledging the plausibility of their statements o Used the statements of others to build a larger theory about a topic o Of good accord • Negative and hostile interactions between students (N) o Drew on negative emotions to make their argument o Undermined the quality of arguments without reason

	5 min	10 min	15 min
Content Integration Are they integrating neuro and NOS – yes (Y), or no (N)	Y / N	Y / N	Y / N
Discussion Quality Circle all that apply Factual (F), Conceptual (C), Analytical (A), Evaluative (E)	F / C / A / E	F / C / A / E	F / C / A / E
Social Interactions small group only (S), large group only (L), or both integrated (I)	S / L / I	S / L / I	S / L / I

Ambiance Positive and supportive (P), negative and hostile (N)	P / N	P / N	P / N
	20 min	25 min	30 min
Content Integration Are they integrating neuro and NOS – yes (Y), or no (N)	Y / N	Y / N	Y / N
Discussion Quality Circle all that apply Factual (F), Conceptual (C), Analytical (A), Evaluative (E)	F / C / A / E	F / C / A / E	F / C / A / E
Social Interactions small group only (S), large group only (L), or both integrated (I)	S / L / I	S / L / I	S / L / I
Ambiance Positive and supportive (P), negative and hostile (N)	P / N	P / N	P / N
	35 min	40 min	45 min

Content Integration Are they integrating neuro and NOS – yes (Y), or no (N)	Y / N	Y / N	Y / N
Discussion Quality Circle all that apply Factual (F), Conceptual (C), Analytical (A), Evaluative (E)	F / C / A / E	F / C / A / E	F / C / A / E
Social Interactions small group only (S), large group only (L), or both integrated (I)	S / L / I	S / L / I	S / L / I
Ambiance Positive and supportive (P), negative and hostile (N)	P / N	P / N	P / N
	50 min	55 min	60 min
Content Integration Are they integrating neuro and NOS – yes (Y), or no (N)	Y / N	Y / N	Y / N

Discussion Quality Circle all that apply Factual (F), Conceptual (C), Analytical (A), Evaluative (E)	F / C / A / E	F / C / A / E	F / C / A / E
Social Interactions small group only (S), large group only (L), or both integrated (I)	S / L / I	S / L / I	S / L / I
Ambiance Positive and supportive (P), negative and hostile (N)	P / N	P / N	P / N

	65 min	70 min	75 min
Content Integration Are they integrating neuro and NOS – yes (Y), or no (N)	Y / N	Y / N	Y / N
Discussion Quality Circle all that apply Factual (F), Conceptual (C), Analytical (A), Evaluative (E)	F / C / A / E	F / C / A / E	F / C / A / E

Social Interactions small group only (S), large group only (L), or both integrated (I)	S / L / I	S / L / I	S / L / I
Ambiance Positive and supportive (P), negative and hostile (N)	P / N	P / N	P / N
	80 min	85 min	90 min
Content Integration Are they integrating neuro and NOS – yes (Y), or no (N)	Y / N	Y / N	Y / N
Discussion Quality Circle all that apply Factual (F), Conceptual (C), Analytical (A), Evaluative (E)	F / C / A / E	F / C / A / E	F / C / A / E
Social Interactions small group only (S), large group only (L), or both integrated (I)	S / L / I	S / L / I	S / L / I

Ambiance Positive and supportive (P), negative and hostile (N)	P / N	P / N	P / N
	95 min	100 min	
Content Are they integrating neuro and NOS – yes (Y), or no (N)	Y / N	Y / N	
Discussion Quality Circle all that apply Factual (F), Conceptual (C), Analytical (A), Evaluative (E)	F / C / A / E	F / C / A / E	
Social Interactions small group only (S), large group only (L), or both integrated (I)	S / L / I	S / L / I	
Ambiance Positive and supportive (P), negative and hostile (N)	P / N	P / N	

Appendix R: Catalytic Group Reflection Prompts

Catalytic Group Reflection Prompt

1. How have your experiences in the focus group contributed to your attitudes about connecting neuroscience and NOS and using those domains of knowledge in science teaching and learning?

2. How do your experiences in the normal class setting (with other students of the course) adhere to or stray from the conversations you have had in the focus groups? Is there space in the large group for you to continue the conversations that you have had in the focus group, or are these experiences largely separate from one another?

Appendix S: Observation Content Categories For Large Group Sessions

Session 1 – Social aspects of science/Value and objectivity in science, The Neuroscience of Memory

List of Content Statements Associated with NOS	List of Content Statements Associated with Neuroscience
1. The nature of science is that it is always changing based on new evidence that is continually supported or refuted by other scientists. 2. The refutation of scientific findings by other scientists causes shifts in the paradigm of science and what scientists believe about the world around them. 3. Shifts in paradigms of science are based on the social backing of specific scientists or research that is funded by people who have access and thus more authority in a society. 4. Scientists have a hard time operating fully objectively because they operate within a scientific paradigm that is constructed by people (socially constructed). 5. Constructing scientific knowledge is an inherently social process not only because it is created and carried out by scientists, but also because of the nature in which that scientific knowledge comes to light. a. Science, if it does rely on the scientific method, is carried out by at least two people, with the goal of publication and transmission of findings to others. Some people argue that because this publication process also contains an aspect of conceptual criticism carried out by other scientists, science itself is objective in nature.	Factual 1. Memories are the reflection of experiences from the recent or remote past. 2. The brain's ability to acquire new declarative (episodic and semantic) memories depend on the hippocampus. 3. Memory retrieval failures can occur either because the information was never encoded into memory, or because the retrieval processes do not allow for successful recovery of the stored information. 4. Retrieval of memories can be enhanced or diminished based on where you are located or what mood you are in. 5. There are two models of memory consolidation: The Standard Model, and Multiple Trace Theory. 6. Multi-modal learning experiences and the similarity of the learning experience to the delayed task allow for a higher chance of retrieval. 7. Memories are based on attentional factors as well as perceived emotional valence. 8. Emotional memories are not always remembered with greater accuracy, although they are remembered more often. Examples of other types of statements that might be made at differing knowledge-based categorical levels Conceptual 1. The medial temporal lobe is important for episodic memory encoding (and thus retrieval) because the hippocampus (part of the medial temporal lobe) is the

<table>
<tr>
<td>6. Objectivity is characteristic of a community’s practice of science rather than the individual’s, and that scientific knowledge is therefore social knowledge.
7. There is a set of shared standards that both define and guide the scientific community in carrying out conceptual criticism of alternative theories, making it hard for the paradigm of science itself to shift.
8. The main goal of the science laboratory is the production of papers, either for education of those outside of the paradigm or for peers that reside within the paradigm; papers are considered the manufactured goods of the science laboratory.
9. There are scientific statements that are considered taken-for-granted fact (type 5 statements) that no one in the paradigm questions; in fact, these type-5 statements often define the paradigm itself. Type-1 statements (on the other side of the spectrum) are speculative statements that take place either at the end of papers or in the discussion.
10. Part of the goal of the science laboratory in the production of papers is also the establishment of type-5 statements, but there is no promise that future qualifications will see it as such.</td>
<td>relay station for all incoming sensory information (usually associated with episodic memories).
2. Statements that: paraphrase, describe, interpret, explain, predict, associate
Analytical
1. Emotion has a higher chance of biasing episodic memory because it draws more on our past experiences and influences what we attend to in that moment (or episode); semantic memory (facts, dates, etc.) has a lesser chance of being biased by emotion, unless certain facts/dates/etc. have emotional significance for us.
2. Statements that: compare/contrast, classify, discriminate, categorize
Evaluative
1. The Multiple Trace Theory better explains memory consolidation than the Standard Model because it accounts for the lack of dependency of semantic memories on the hippocampus over time.
2. Statements that: appraise, judge, support, defend, find errors</td>
</tr>
<tr>
<td colspan="2">List of Content Integration Statements of NOS and Neuroscience</td>
</tr>
<tr>
<td colspan="2">1. Neuroscience is an interesting example of how science is constantly evolving and changing because there are many neurologically sound theories that explain the same principles in different ways, all of which have individual merit.
2. Shifting the neuroscience paradigm to include new theories is hard because many people that work within this neuroscientific paradigm have an accepted set of standards from which they operate.
3. The construction of neuroscientific knowledge is socially constructed by scientists who constantly re-test the work of others, pushing the domain forward.</td>
</tr>
</table>

4. Scientists within the neuroscience paradigm communicate through research papers that document what they do in their own laboratories and influence future laboratory endeavors. 5. There is no guarantee that the work produced in a neuroscientific paper will maintain its merit over time. 6. Members of the neuroscience community that have greater authority highly influence what theories are accepted as the standards for the paradigm.

Session 2 – Science Laboratory in Context, The Neuroscience of Attention

List of Content Statements Associated with NOS	List of Content Statements Associated with Neuroscience
1. The nature of laboratory work in science classrooms have changed tremendously from the 1960's to today. 2. The STEM-education initiatives in the 1950's hoped for open-ended scientific inquiry to take place of the 'cookbook' approach to the scientific process, but this open-ended approach assumed too much of students intellectually and did not offer enough scaffolded support for students to succeed. Additionally, teachers were not offered enough support to successfully teach in a style of open-ended inquiry. As a result, teachers continued to rely on the cookbook approach to teaching in science laboratories. 3. The era of the 1980's to the 1990's adopted a constructivist view of the science laboratory, where conceptual change strategies were used to develop laboratory activities. Here we saw the rise of the scientific method and the predict-observe-explain model. 4. Today, the science education community is taking into larger consideration the social and cultural aspects that contribute to science, with the goal of science laboratories being to communicate with other scientists in a unique way. 5. There are gaps between what science education literature desires and what students experience in science	Factual 1. Attention is the ability to prioritize some things while ignoring others. 2. Attention can either be covert/overt, or top-down/bottom-up. 3. Attention has a limited capacity, and we prioritize what we attend to for a variety of reasons. 4. There are two models of attention: the early selection model and the late selection model. These models vary by when sensory inputs are selected for further processing or thrown out. 5. Measuring the effect of attention on processing occurs by examining how people respond to targeted stimuli under differing conditions of attention. 6. People respond faster to stimuli when they have been primed to look in that direction. 7. Attention to one hemifield (visual space) activates the opposite side of the brain. For example, if you see something in the right hemifield, the left side of the brain activates. 8. Controlling attention happens in either a top-down or bottom-up fashion. 9. There are two networks of attentional control, each with different functions that produce normal behavior: the dorsal attention

<table>
<tr><td>laboratories; many teachers still rely on the scientific method.
6. What it means for students ‘to know’ in science classrooms is to be able to develop arguments based on scientific evidence; over time, students become masterful participants of the scientific enterprise.
7. Taking a sociocultural perspective on science education means viewing science, science education, and research on science education as human social activities conducted within institutional and cultural frameworks.
8. The sociocultural framework includes all the social entities within which we live, including social organizations, family/school/church groups and even city/state/economy-based groups. These entities help us to make sense of the world around us.
9. The most basic belief of the sociocultural perspective is that we do not know why we act as we do, rather, we only know a few local reasons that arise from the functioning of our actions in a far larger and more distant context and on a longer time scale.
10. A choice between two scientific explanations can only be made if both belong to a common tradition, with agreed-upon rules of evidence and argumentation. This ideal will require a conceptual change for all those who interact with science.
11. We can ask students to change their beliefs about science, but not without awareness that we are inviting them to join a subculture and a particular system of beliefs and values.</td>
<td>network and the ventral attention network.
10. Emotion guides what items we perceive and attend, with negative items granting a faster reaction time.
Conceptual
1. The quickness with which we complete a task is connected to the specialization of the right versus the left hemisphere.
Analytical
1. Although there is dominance for certain tasks on one side of the brain over the other, knowledge of that task is still present on both sides of the brain.
Evaluative
1. The early selection model and the late selection model both have merit in explaining selective attention because I believe that some items can be thrown out early whereas others take more time to figure out if they have enough importance to pay attention to them.</td></tr>
<tr><td colspan="2">List of Content Integration Statements of NOS and Neuroscience</td></tr>
<tr><td colspan="2">1. Neuroscientists view their work as operating within the institutional framework of society, because it is based on how people function and interact with one another.
2. Neuroscientific research has brought scientific evidence into the argument that people of a variety of cultures cognitively function in a variety of ways, altering how they perceive and attend to the world.</td></tr>
</table>

3. Neuroscience cannot operate fully without considering the social and cultural aspects of people upon whom the research is being conducted. 4. Social and cultural aspects of people are not considered in the creation and perpetuation of the standards set to regulate neuroscientific research. 5. Neuroscience uses social and institutional frameworks to attempt to understand differences in their findings, but it does not influence scientific methodology.

Session 3 – Epistemologies in Science, The Neuroscience of Emotion Regulation

List of Content Statements Associated with NOS	List of Content Statements Associated with Neuroscience
1. Epistemology is the study of understanding how we know what we know. 2. There are three broad perspectives of epistemology in science education: a. Disciplinary Epistemology: i. students have knowledge which develops in a manner similar to that of science itself ii. There are two large foci to be considered: Theory (students adopt novel ideas/phenomena into their existing schema) and Legitimization (students accept the content presented in the classroom) b. Personal Epistemology: i. every student has an individualized means of structuring their knowledge and of activating or altering that structure c. Epistemology as Social Practice: i. Utilizing knowledge to yield particular behaviors or artifacts ii. Examines interactions between students and the artifacts produced in those interactions to determine how students are using what they know, which is	Factual 1. Emotion is an identifiable feeling state involving physiological arousal, a cognitive appraisal of the stimulus, and an outward behavior expressing the feeling state. 2. There are at least 4 theories on how emotions occur: the James-Lange theory, Cannon-Bard theory, the Schachter-Singer theory, and constructivist theory. 3. The amygdala has an impact on emotional and social behavior. 4. There are a number of ways we can regulate our emotional experiences, including selective attention and cognitive reappraisal. a. We can change which emotions we experience, how intensely we experience them, and in what situations we experience them in. 5. Cognitive reappraisal does not completely eliminate the emotional response to a stimulus. 6. The pre-frontal cortex is associated with increasing and decreasing emotional sensitivity. It is also associated with changes in amygdala activity. 7. Cognitive control is a higher-order cognitive task that relies on the

<table>
<tr>
<td>seen as a statement of how they know it
3. Four themes emerge from the study of these three perspectives of epistemology:
a. Students’ epistemologies can only be represented through products and interactions in science
b. The evaluation of students’ understandings only comes from observation and analysis of those products and interactions
c. Epistemology is closely related to identity
d. What counts as knowledge continues to evolve over time
4. People think about scientific content and what it means to learn that content in a variety of ways:
a. As by a set of random scientific pieces or a coherent system of thought
b. As either a collection of mathematical formulas, or a collection of scientific concepts
c. Learned as dictated by an authority, or by acquisition of knowledge via independent experiences of situations
5. Students have many reasons for thinking this way, including:
a. The success in a course is related to content knowledge and not epistemological knowledge
b. Some students have greater cognitive reasoning abilities than others, leading to a greater understanding of the epistemologies of science
c. Their goal in taking the course may be just to get a good grade and not to understand the scientific system at hand</td>
<td>interplay between the pre-frontal cortex and the amygdala.
8. The pre-frontal cortex is also associated with many other tasks that we think of that come with maturation, including decision making and logical reasoning.
9. There are many downfalls of not being able to regulate our emotion, including poor academic performance, an increase in risky behaviors, social isolation, and at the most extreme, psychopathies.
Conceptual
1. There are basic emotions that help to explain how varying cultures come to agree on outward behaviors that symbolize the same emotions.
2. The most successful emotion regulation mechanism is cognitive reappraisal because we are changing the emotional impact of that situation.
Analytical
1. The Cannon-Bard theory is different from the James-Lange theory in that the JL theory indicates that physiological changes are caused by the stimulus, leading to behavioral changes, whereas the CB theory posits that physiological changes and emotional changes caused by the stimulus equally contribute to behavioral changes.
Evaluative
1. I support the argument that cognitive reappraisal is the best emotion regulation mechanism because it forces the mind to process stimuli through cognitive mechanisms instead of emotional mechanisms.</td>
</tr>
<tr>
<td colspan="2">List of Content Integration Statements of NOS and Neuroscience</td>
</tr>
</table>

1. What counts as knowledge in neuroscience is constantly changing over time based on the accumulation of new scientific evidence and the influx of scientists into the domain.
2. Students learning neuroscience may view that content as authoritarian and unquestionable, while neuroscientists may view the domain as a system of concepts that is fluid and subject to change.
3. Neuroscience helps to provide a scientific framework for epistemology because it focuses on the production and analysis of knowledge held by others.

Appendix T: Script for Soliciting Recruitment for Research Assistant

My name is Kristina Hopkins, and I am a Doctoral Candidate in Science Education. I am currently working on my dissertation (IRB 17-406), and I am soliciting a Research Assistant to conduct observations for my study. These observations will take place in MSTC 5041 (Nature and Practices of Science) for two hours one a week, over the course of 4 weeks. There will be an observation rubric that the R.A. will use to complete the observations. I will also hold a brief, one-hour training for the R.A. to familiarize them with the layout of each section of the observation rubric. Compensation will come in the form of $15 an hour (for a total of $135 dollars, 8 hours of observations plus a one-hour training).

Please email me (kkh2124@tc.columbia.edu) if you are interested!

Appendix U: Training Guide for the Use of Observation Protocol

1. What are the duties of a Research Assistant?
    a. To assist the principal investigator (PI) on the collection of data
2. What is this research project about?
    a. Rationale: students who take courses on NOS have a hard time retaining what they learn, as it is highly theoretical, and lacks both practical applications and a fruitful context to understand the theory
    b. Objective: to see if neuroscience provides a fruitful context for teachers to carry over NOS to teacher pedagogy and lesson planning
    c. RQ: Does neuroscience serve as a fruitful foundation for pre-service and in-service teachers to learn about the nature of science as it applies to classroom practice?
3. Why is a research assistant necessary?
    a. Part of the data that I am collecting for this study is based on classroom observations, using a protocol that I have developed
    b. I will be teaching/leading the course for the first hour and engaging with students in the class for the second hour
        i. I cannot conduct observations of myself or other students
4. What does your role look like?
    a. Observations will take place for the 1st, 2nd, 3rd, and 4th large group sessions
    b. 2-hour sessions (except for the 4th) on Wednesdays from 5 p.m. – 7 p.m.
        i. 0-30 minutes – mini lecture; 30-60 minutes – lesson study; 60-100 minutes discussion
        ii. In the 2nd – 4th sessions, there will be devoted time for small group 'share out'
    c. Remunerations
5. Observation Protocol
    a. 4 categories: Content Integration, Social Interactions, Discussion Quality, Ambiance
        i. Use of multiple coding
        ii. Content Integration – list sets
    b. Measured on a time-scale
        i. Every 5 minutes, you will write down your observations