

DEVELOPMENT OF NATURE OF SCIENCE IDEAS THROUGH AUTHENTIC
SCIENTIFIC RESEARCH

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

2012

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To my Lord and Savior Jesus Christ: “And whatever you do in word or deed, do it all in the name of the Lord Jesus, giving thanks to God the Father through him” (Colossians 3:17).

To my wonderful and beautiful wife Rachael for loving me, believing in me and sacrificially supporting me through this process

To my remarkably special daughter Leah for constantly and joyfully reminding me that there is more than one way to “see” the world

ACKNOWLEDGMENTS

First, I wish to thank my advisor Dr. Troy Sadler, without whom I never would have left the safety and comfort of my chemistry classroom. Troy introduced me to my passion for educational research and taught me what it means to be a professional within the science education community. The lessons I have learned from Troy are invaluable and will never be forgotten. Troy has been a wonderful mentor, colleague and friend.

Additionally, I wish to thank the rest of my committee members. Dr. Rose Pringle, Dr. Dorene Ross and Dr. Stephen Miller provided me a great deal of support throughout my doctoral studies and my dissertation research. I particularly want to thank Dorene for setting up an accountability group among my class of doctoral students to push us to keep moving through the data analysis and writing process.

I offer a special thanks to Dr. Mary Jo Koroly and all of the staff of the Center for Precollegiate Education and Training at the University of Florida. Additionally, I wish to thank all of the staff and student participants of the Student Science Training Program of the summer of 2011. I truly consider all of them to be co-researchers with me in this project.

This dissertation would not have been written without the impact of the faculty and former and current doctoral students of the School of Teaching and Learning at the University of Florida. I want to thank Dr. Kent Crippen for always keeping his door open and taking the time to listen to me and provide valuable advice at each stage of the data analysis process. I will always consider Kent to be an honorary member of my dissertation committee. To the doctoral students who have gone before me (Dr. Jeff Boyer, Dr. Jenn Mesa, Dr. Michelle Klostermann, Dr. Jonathan Bostic, Dr. Katie Milton

Brkich and Dr. Chris Brkich), thank you for the wonderful examples you have been to me both personally and professionally. I have learned so much from each of you. Your dissertations were a pleasure to peruse and provided me with wonderful models for my own writing. To those in my current graduating class whom I have grown close with (Fred Nelson, Karina Hensberry, Katrina Short and Katie Tricarico) thanks for walking through this with me. Finally to those doctoral students not done yet (Tim Barko and Julie Brown), thanks for your friendship and your encouragement. Keep working hard and do not give up. A particular thanks goes to Tim for helping me collect and analyze the data for this study. I could not have done this without him.

I would also like to thank my family. In particular, I wish to acknowledge my parents (Ron and Jeanie Burgin and John and Nancy Howell) for the countless ways that they have shown their love to me throughout my doctoral studies. Additionally, I would like to thank all of my siblings (Sarah, Patty, Andrew, Denise, Jonathan and Joseph) for being there for me when I needed each of them. I appreciate you all so much. I am particularly grateful for my brother Andrew. I am glad you chose UF and that we got to be students together this past year. Go Gators!

Finally, I would like to thank my wife Rachael whom I love with all of my heart. The past three years of my doctoral studies have coincided with some of the most heartbreaking tragedies and inexpressible joys in our life. Rachael was my stability during this rollercoaster ride. I am excited to embark on this next great adventure with her.

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LIST OF ABBREVIATIONS

AAAS	American Association for the Advancement of Science
AESP	Authentic Experiences in Science Program
ISS	Ideas about Science Survey
NOS	Nature of Science
NRC	National Research Council
PI	Principle Investigator
VNOS	Views of the Nature of Science Questionnaire

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

DEVELOPMENT OF NATURE OF SCIENCE IDEAS THROUGH AUTHENTIC
SCIENTIFIC RESEARCH

By

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August 2012

Chair: Rose Pringle

Major: Curriculum and Instruction

Understanding the ways in which scientific knowledge develops, or the epistemology of science, is believed to be a crucial component of scientific literacy. This construct is more formally known as Nature of Science (NOS) within the science education community. The merits of three different approaches to NOS teaching and learning in the context of authentic scientific research on high school student participants' NOS ideas were explored in this study. These approaches were an explicit/reflective approach, a reflective approach and an implicit approach. The effectiveness of explicit approaches over implicit approaches has been demonstrated in school contexts, but little is known regarding the merits of these approaches when the practices that learners engage in are highly authentic in the ways in which they model the work of professional scientists. If an implicit approach yields positive impacts in authentic contexts, then which specific factors within those contexts are influential in doing so?

The Authentic Experiences in Science Program (AESP), a summer program designed for high school students offered at a major research university, offered a wonderful context for an investigation of these issues. In this program, high school

students worked for an extended period of time in a research scientist's laboratory on an authentic research project. Additionally, seminars offered through the program provided a venue for the implementation of the three aforementioned NOS teaching and learning approaches. An open-ended questionnaire designed to assess respondent NOS ideas was administered to 30 participants of the AESP both at the beginning and again at the end of the program. From those thirty, six case study participants were selected, and through a series of observations and interviews, influential factors impacting their NOS ideas within their specific laboratory placements were identified.

Results of categorical data analysis of the questionnaires revealed that the changes in NOS ideas exhibited by the participants who experienced the explicit/reflective approach were significantly different from the changes in NOS ideas exhibited by the participants who experienced either of the other two approaches. Specifically, changes related to participants' understandings of the distinctions between theories and laws in science and the myth of the scientific method were significantly and positively impacted for the participants who experienced the explicit/reflective approach. Additionally, case study participants who experienced either of the other two approaches demonstrated changes in their understandings of many NOS aspects (e.g. subjectivity, creativity, empirical NOS). Authentic action on the part of these participants was linked to these positive NOS changes. That authentic action was more influential when the participants were treated in authentic ways and developed feelings of authenticity. The findings prompted a discussion of implications and recommendations for NOS teaching and learning in both school contexts and authentic contexts.

CHAPTER 1 THE PROBLEM

Introduction

The primary goal of science education is the preparation of a scientifically literate society (American Association for the Advancement of Science, 1993; National Research Council, 1996). Both the *Benchmarks for Science Literacy* (American Association for the Advancement of Science (AAAS), 1993) and the *National Science Education Standards* (National Research Council (NRC), 1996) were created in an effort to provide guidelines that would enable this goal to be reached for all elementary and secondary students of science in the United States. Participation in the practices of science and the development of understandings about science as a way of knowing are two important components of the suggestions offered in these documents and in the latest reform document that will provide a framework for the next generation of science standards (NRC, 2012). The practices of science are typically referred to as scientific inquiry and understandings about science as a way of knowing are more formally known as Nature of Science (NOS). The term “scientific inquiry” is defined in this report as an active process of data analysis in order to answer an empirical question that can occur in various settings including school-based laboratories along a continuum of epistemic involvement on the part of the learner (Germann, Haskins & Auls, 1996; Herron, 1971; Schwab, 1962). Epistemic involvement is defined in this study as the degree to which a learner takes an active role in the development of guiding research questions and the decision-making process that takes place as scientific inquiries are conducted. NOS as a construct will be defined in further detail in a subsequent section of this chapter.

Scientific inquiry and NOS are overlapping constructs in science education reform documents (NRC, 2007; 2012). In them, it is clear that science educators and other stakeholders in science education adhere to the belief that “doing” science, on the part of science learners of all ages, is at least partially related to their understandings of how knowledge is developed in the enterprise of science. This belief is clearly articulated in *Taking Science to School* (NRC, 2007). In a review of the literature, citing multiple research studies, the NRC (2007) concludes that, “with appropriate supports for learning strategies of investigation, children can engage in designing and conducting investigations that enable them to understand science as a way of knowing” (p.182). Several science educators disagree with the notion that participation in science practice alone will have an impact on learners’ NOS understandings on the basis of limited supporting empirical evidence (Aydeniz, Baksa & Skinner, 2010; Bell, Matkins & Gansneder, 2010; Khishfe & Abd-El-Khalick, 2002; Lederman, 2007; Yacoubian & BouJoade, 2010).

It has also been argued that the amount of overlap between participation in and understanding of the construction of scientific knowledge is dependent on the similarities between school science and professional science. “If students themselves participate in scientific investigations that progressively approximate good science, then the picture they come away with will likely be reasonably accurate” (AAAS, 1993, p.4). However, a number of science educators question the degree to which school science actually does resemble professional science and therefore naturally question the impact of scientific inquiry on NOS understandings in these settings (Chinn & Malhotra, 2002; Hogan, 2000; Osborne, 2002; Sandoval, 2005).

Where science educators seem to be in unanimous agreement with science education reform documents is on the stated value of experiences in scientific inquiry as contexts for reflective thought on NOS (Lederman, 2007). “By gaining lots of experience *doing* science, becoming more sophisticated in conducting investigations, and explaining their findings, students will accumulate a set of concrete experiences on which they can draw to *reflect* on the process” (AAAS, 1993, p. 4). When students are provided with opportunities to reflect on the similarities and the differences between their own participation in science practices and the ways in which professional scientists construct knowledge, then perhaps understandings of NOS can be impacted (Sandoval, 2005). This emphasis on reflection within the science education community has been informed by the works of Dewey (1933), Schön (1983; 1987) and Zeichner and Liston (1987) and has resulted in reflective thought being defined as an active decision making process taking place in various situations for the purposes of empowerment.

This study aims to examine the relationship between supported participation in scientific inquiry (including supports for reflection) and the development of understandings about science as a way of knowing. The remainder of this chapter focuses on a discussion of the key research issues that will be addressed in this investigation (NOS teaching, learning and assessment; practical and formal epistemologies of science; and authenticity in science education). Additionally, this chapter contains a discussion of research apprenticeships and other authentic research experiences in science as a context for the exploration of these research issues. The chapter concludes with an overview of the theoretical framework for the study, the problem on which this research is focused, the specific research questions and sub-

questions driving this investigation and a rationale for them, as well as the significance and limitations of this study.

Research Issues

Nature of Science (NOS)

The development of sophisticated NOS understandings has been and still is a nearly universally valued objective of K-12 science education for a variety of reasons. NOS has been historically defined by science educators as “the values and assumptions inherent to the development of scientific knowledge” (Lederman & Zeidler, 1987, p. 721). As previously discussed, the development of appropriate understandings of NOS among K-12 science students has been connected to scientific literacy and as such is featured prominently in science education reform documents (AAAS, 1993; NRC, 1996). It has been argued that a sophisticated understanding of science (including NOS) by the general public results in benefits for, amongst other things, science, economies, individuals, democracy, society and morality (Thomas & Durant, 1987). Driver, Leach, Millar and Scott (1996) summarize these benefits when they make economic, utilitarian, democratic, cultural and moral arguments for the importance of NOS understandings. Although the empirical evidence supporting these arguments for NOS are scant (Lederman, 2007), research indicating that student-held conceptions of NOS are linked to decision making strategies regarding socio-scientific issues such as global climate change lend them some merit (Sadler, Chambers & Zeidler, 2004; Zeidler, Walker, Ackett & Simmons, 2002).

Consensus aspects of NOS

Perhaps the clearest rationale for an inclusion of NOS instruction in K-12 education is the consistent demonstration of inadequate understandings of NOS by both

students and teachers of science (Lederman, 1992; Lederman, 2007). In order to make such claims and evaluate any intervening efforts to influence positive change in NOS understandings, it becomes important to identify and establish consensus aspects of NOS that can be explicitly targeted for both instruction and assessment.

A number of science educators have made efforts to generate lists of consensus aspects of NOS that are commonly held beliefs and values among informed stakeholders within the science education community (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002; Osborne, Collins, Ratcliffe, Millar & Duschl 2003; Sandoval, 2005; Schwartz & Lederman, 2008). Lederman et al. (2002) identified seven aspects of NOS that were used to generate a questionnaire for assessing NOS understandings. These consensus aspects are the empirical nature of scientific knowledge, the distinctions and relationships between scientific theories and laws, 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 the scientific method and the tentative nature of scientific knowledge. Sandoval (2005) condensed this list into four aspects of NOS. These are the construction of scientific knowledge, the diversity of scientific methods, the different forms of scientific knowledge (including hypotheses, models, theories and laws) and that scientific knowledge varies in certainty. It is Sandoval's (2005) list that was used to organize the discussion of NOS in the reform document *Taking Science to School* (NRC, 2007). Regardless of the specific number of NOS aspects, consensus lists such as these hold many common features. Chief among them are an understanding of the social construction of scientific knowledge, the vast

diversity of methods employed by scientists as they construct scientific knowledge and the ever-evolving state of scientific knowledge.

The existence of such consensus aspects has been called into question on the grounds of different perspectives among philosophers of science regarding which aspects to include (Alters, 1997). Others argue that more agreement than disagreement actually does exist and that any points of contention are regarding abstract philosophical perspectives that have little bearing on K-12 science education (Lederman, 2007; Sandoval, 2005; Smith, Lederman, Bell, McComas & Clough, 1997). In fact, empirical evidence has recently revealed that there does exist at least some general level of consensus regarding various aspects of NOS among a variety of stakeholders in science education including philosophers of science (Osborne et al., 2003) and that practicing scientists, regardless of their specific science discipline, hold more sophisticated understandings regarding many of these aspects than not (Schwartz & Lederman, 2008; Wong & Hodson, 2009; Wong & Hodson, 2010).

Teaching and learning of NOS

Although science educators have established some consensus regarding sophisticated understandings of various NOS aspects, they continue to debate over how to best develop such understandings among K-12 science students. In general, one of two approaches to the teaching and learning of NOS are taken. These are the implicit approach and the explicit/reflective approach.

The first of these, the implicit approach, is based on the assumption that participation in scientific inquiry in and of itself will have a positive influence on NOS understandings. Although participation in hands on science is often assumed by science educators to be related to the development of NOS, there is very little empirical

evidence that supports such a claim (Lederman, 2007). In fact, research indicates that an implicit approach is not linked to the development of informed NOS understandings even in the context of a problem-based high school science course (Moss, 2001).

The second approach to impacting learner understandings of NOS is the explicit/reflective approach. This approach involves explicit instruction of consensus aspects of NOS and provides opportunities for specific learner reflection on them as they relate to classroom-embedded activities (Lederman & Abd-El-Khalick, 1998) that may or may not involve participation in science inquiry. This approach is not to be confused with traditional forms of direct instruction in which a teacher acts as an authoritarian figure telling students what the true aspects of NOS are. Rather, the explicit in the explicit/reflective approach refers to an intentionality regarding the planning of lessons to allow learners to meet explicit instructional objectives that relate to accepted NOS understandings. Empirical research has demonstrated the effectiveness of this approach in a variety of instructional settings (Akerson & Volrich, 2006; Akerson, Abd-El-Khalick & Lederman, 2000; Bell et al., 2010; Khishfe & Abd-El-Khalick, 2002; Yacoubian & BouJaoude, 2010).

Very few studies have attempted to directly compare the impact of both of these approaches. Those studies that have been conducted in secondary school science classrooms reveal more substantial NOS gains as a result of an explicit/reflective approach when compared to any gains in NOS from an implicit approach due to participation in science inquiry alone (e.g. Khishfe & Abd-El-Khalick, 2002; Yacoubian & BouJaoude, 2010).

Assessing NOS

Traditionally, NOS understandings have been assessed by utilizing pen and paper instruments on which participants respond to multiple choice questions or rank their agreement or disagreement with given statements which can then be analyzed quantitatively (Cooley & Klopfer, 1963; Rubba & Anderson, 1978). The validity of using such instruments to assess understandings of NOS has been called into question on the basis of the design of these instruments (Lederman, Wade & Bell, 1998). Lederman et al. (1998) argue that these instruments measure the degree to which student understandings of NOS align to the perspectives of the developers of the instruments themselves and do not provide students with an opportunity to express and explain their own perspectives of NOS. In response to such critiques, new open-ended questionnaires have been developed that provide students with an opportunity to describe their own feelings in regard to consensus NOS aspects (Lederman et al., 2002). When coupled with follow-up interviews, open-ended questionnaires can be qualitatively analyzed in order to provide a more accurate portrayal of student NOS beliefs.

Practical and Formal Epistemologies of Science

There exists a growing perspective among science educators that student understandings of NOS are situational (Elby & Hammer, 2001; Hogan, 2000; Sandoval, 2005). Central to this perspective is the idea that students' personal experiences in science shape an understanding of scientific epistemologies that may not be necessarily linked to their understandings of how professional scientists construct knowledge and the nature of that knowledge. Hogan (2000) uses the terms proximal and distal knowledge about NOS when discussing this situated perspective. Students'

proximal understandings of NOS involve their own perceptions of their personal involvement in the generation of scientific knowledge. Distal understandings refer to student conceptions of a distant professional science within which they may or may not have had direct experience. Sandoval (2005) makes a similar argument when he suggests that students hold both practical and formal epistemologies of science. Practical epistemologies (like proximal knowledge) are students' ideas about their own inquiry and the associated creation of scientific knowledge. Formal epistemologies (like distal knowledge) are students' beliefs about the creation of knowledge within professional science.

Implications for teaching and learning NOS

If students potentially hold two distinct views about NOS, then this has implications for the ways in which NOS is taught in K-12 science education. Participation in inquiry alone may not influence student understandings of professional science if student understandings of NOS in these contexts are compartmentalized. It may be the case that students' practical conceptions of NOS are so far removed from their formal conceptions of NOS that it would be quite challenging to influence both types of understandings simultaneously. Empirical evidence seems to point to the existence of such a challenge in school settings due to the contextual nature of NOS understandings (Roth & Roychoudhury, 1994; Sandoval & Morrison, 2003). It is not altogether surprising then that interventions which may in fact be influencing student practical conceptions of NOS do not seem to be impacting student understandings of formal NOS (Khishfe & Abd-El-Khalick, 2002; Yacoubian & BouJaoude, 2010). One suggested response is to provide explicit opportunities for discourse about NOS in an effort to bring student talk during their own inquiry and student talk about professional scientific practice closer

together (Sandoval & Morrison, 2003). Engaging students in reflective thought could be a key component of facilitating the teaching and learning of both practical and formal NOS understandings (Sandoval, 2005).

Implications for assessing NOS

The commonly used formal assessments of NOS (Cooley & Klopfer, 1963; Lederman et al., 2002; Rubba & Anderson, 1978) are believed by some to be attempts to measure student conceptions of the nature of professional scientific knowledge generation without attending to students' personal conceptions of NOS (Hogan, 2000; Sandoval, 2005). Hogan (2000) discusses how these assessments focus almost exclusively on measures of distal NOS understandings without providing opportunities for students to make explicit connections to their own participation in science. Sandoval (2005) similarly argues that these assessments are disconnected from student participation in the practice of science and that they are based on an "assumed coherence of beliefs" (p.644). In other words, these assessments assume that student responses to questions about a distant professional science reveal learner conceptions about their own participation in science inquiry and knowledge construction. What students believe about their own participation in science and their perspectives of professional science are one and the same from this point of view. If students hold distinct views of NOS in different contexts, then such an assumed coherence is not necessarily valid. Sandoval suggests a more ethnographic approach to the assessment of NOS that is embedded in the context of authentic scientific practice. This approach involves the use of open-ended interviews and the study of student discourse and artifacts produced as a result of student participation in scientific research.

Authenticity in Science Education as Related to NOS

Authenticity in science education is no easy term to define. As Bencze and Hodson (1999) point out, authenticity “continues to remain an elusive and problematic notion, with diverse meanings and curriculum implications” (p. 522). Perhaps this difficulty in reaching a consensus understanding of authenticity is due to the situated nature of scientific experiences within different cultures that are experiencing them (Martin, Kass & Brouwer, 1990). What is authentic in one context could be quite inauthentic in another. The following discussion of authenticity will focus specifically on authenticity within science inquiry experiences in school settings.

Authenticity conceptualized

One of the earlier attempts at defining authenticity in science education was made by Roth (1995). According to Roth, “School activities, to be authentic, need to share key features with those worlds about which they teach” (p.xiii). Roth listed five key features that scientific inquiries conducted in school settings ought to share with professional science practice in order for them to be classified as authentic. These characteristics are the ill-defined nature of the problem driving a scientific investigation, the uncertainty accompanying the social nature of scientific knowledge generation, a taking into account the prior knowledge of the learners, participation by the learners within a community of inquiry and the presence of more knowledgeable experts within that community of inquiry from whom learners can gain deeper understanding of the scientific knowledge involved in their inquiry.

Chinn and Malhotra (2002), similarly argue that authentic scientific inquiry in school settings ought to closely resemble the actual work of practicing scientists. They provide a theoretical framework for evaluating the authenticity of inquiry tasks that is

based on the cognitive processes involved in their enactment and the epistemology that guides them. The cognitive processes involved in authentic inquiry according to Chinn and Malhotra (2002) are the generation of research questions, the designing of studies, observation making, explaining results, developing theories and studying other scientists' work. The epistemology guiding authentic inquiry includes the theory building and revising purposes of scientific research, the coordination of data with scientific theory, the theory-laden nature of research methods, rational responses to anomalous data, nonalgorithmic and uncertain reasoning and the social construction of knowledge.

An additional characteristic of authentic scientific inquiry discussed by science educators is the centrality of language (Duschl & Osborne, 2002; Osborne, 2002). In particular, the practice of professional science depends on specific forms of discourse. These involve certain structures for argumentative conversation and written communication within authentic scientific inquiries.

Buxton (2006) discusses a canonical perspective regarding authentic scientific practice in school settings. This perspective relies on stakeholders outside of the realm of education, namely the professional scientific community, to provide the parameters of authenticity. The parameters include both the questions and the methods that drive scientific inquiry. Buxton (2006) identifies the work of Chinn & Malhotra (2002) as being representative of this perspective. This present study takes a canonical perspective of authenticity in science education.

According to the canonical perspective of authenticity, the typical school science activity is far from authentic due to its dissimilarities to professional science. A number of reasons are given for the differences between scientific inquiry in school settings and

the practices of professional science that result in this inauthenticity. Among these reasons are an over-reliance on highly structured curricular laboratory activities that require very limited epistemic involvement on the part of learners (Chinn & Malhotra, 2002; Herron, 1971; Hofstein & Lunetta, 2004); institutional constraints of public schools including limits in resources, inflexible scheduling, unsupportive administrators and large class sizes (Abd-El-Khalick, BouJaoude, Duschl, Lederman, Mamlok-Naamon, Hofstein, Niaz, Treagust & Tuan, 2004; Hofstein & Lunetta, 2004); and the pressure faced by science teachers to use laboratory activities as a pedagogical tool to deliver scientific content in order to prepare students to perform well on high-stakes standardized assessments (Abd-El-Khalick et al., 2004; Bencze & Hodson, 1993; Haigh, France & Forret, 2005).

Bridging the gap between practical and formal epistemologies

It follows from the above discussion of canonical authenticity, that authenticity may be a factor that bridges the gap between formal and practical epistemologies of science (Sandoval, 2005). In situations where the “doing of science” can be said to be canonically authentic, then the “assumed coherence of beliefs” (Sandoval, 2005, p. 644) between formal and practical epistemologies of science becomes a more valid assumption. When students have practical experiences conducting work that closely resembles that of professional scientists, then their practical understandings of NOS are more closely related to their formal understandings of NOS. This relationship between practical and formal epistemologies of science in authentic contexts has implications for the teaching, learning and assessment of NOS. For example, assessments designed to measure student conceptions of formal NOS become valid tools for examining the

impacts of participation in scientific inquiry on student conceptions of practical NOS when the context is an authentic one.

Research Apprenticeships as Authentic Contexts for Exploration

Recently, the science education community has recognized the value of experiences outside of the formal science curriculum in introducing secondary students to authentic scientific practices (Braund & Reiss, 2006). One emerging extra-curricular experience in science education is that of the research apprenticeship. Research apprenticeships allow learners to work “at the elbows” of working scientists in a professional setting outside of the context of the traditional curriculum on professional scientific research (Barab & Hay, 2001). Apprenticeship experiences typically take place in working science laboratories on university campuses where the learner is included within a particular laboratory research group and is mentored by a professional scientist within that group as they work together on a meaningful scientific inquiry project. The participants in these research projects seek previously unknown solutions to ill-defined questions or problems, the results of which hold value to the broader scientific community. In addition to the specific research investigation within a working science laboratory, some research apprenticeships are accompanied by extra-laboratory experiences such as seminars where students are introduced to a variety of topics that may include an explicit examination of NOS constructs (Schwartz, Lederman & Crawford, 2004). Due to the professional context in which scientific inquiry is conducted in a research apprenticeship and the ill-defined nature of the research question being investigated, these experiences are among the most canonically authentic experiences in which a secondary learner can participate.

A recent review of the literature presents an overview of the empirical evidence indicating that research apprenticeships have the potential to impact secondary student discourse practices, understandings of NOS, scientific content knowledge, science motivation and confidence and career aspirations among other reported benefits (Sadler, Burgin, McKinney & Ponjuan, 2010). Of particular interest to this present study are those empirical research studies discussed in the literature review mentioned above that specifically investigate the impact of participation in research apprenticeships on learner conceptions of NOS (Barab & Hay, 2001; Bell, Blair, Crawford & Lederman, 2003; Bleicher, 1996; Charney, Hmelo-Silver, Sover, Neigeborn, Coletta & Nemeroff, 2007; Richmond & Kurth, 1999; Ritchie & Rigano, 1996; Ryder & Leach, 1999; Schwartz et al., 2004). Most of the studies investigate the impact of an implicit approach to NOS teaching and learning in these contexts. Only two of the studies specifically investigate the impact of an explicit/reflective approach to NOS teaching and learning during a research apprenticeship (Charney et al., 2007; Schwartz et al., 2004). None of the studies systematically compare the impact of varying approaches to NOS teaching and learning in the context of a research apprenticeship as do studies investigating this relationship in the context of school science (Bell et al., 2010; Khishfe & Abd-El-Khalick, 2002; Yacoubian & BouJaoude, 2010). Additionally, the majority of these studies rely on qualitative analysis of participant self-reported data in making claims about the impact of research apprenticeship programs on NOS understandings. That being the case, a few studies use more targeted questionnaires and follow-up interviews as NOS assessments in these contexts (Bell et al., 2003; Bell et al., 2010; Schwartz et al., 2004).

Theoretical Framework

The theoretical framework for this study is based on a cognitive apprenticeship model (Brown, Collins & Duguid, 1989) and situated learning theory (Lave & Wenger, 1991). The idea behind both of these perspectives is that learning and cognition are situated and cannot be understood apart from the context and culture in which they take place. Situated learning has implications for the notions of authenticity as discussed above. Brown et al. (1989), discuss authentic experiences as, “coherent, meaningful and purposeful activities...defined as ordinary practices of the culture” (p. 34). Such authentic experiences are quite typical of research apprenticeships and are even possible in traditional school settings. Brown et al. (1989) discuss the possibilities of a cognitive apprenticeship model in school settings where teachers mentor their students as problems are solved using the same “cognitive tools” used by members of a particular culture (e.g. science). Lave and Wenger (1991) describe how a learner within an apprenticeship-type experience transitions from an outside observer to an insider with the full rights and responsibilities of any other member within a community of practice. They refer to learning as “legitimate peripheral participation” within such a community of practice.

It follows from this theoretical lens that when learners participate in canonically authentic scientific inquiry, they themselves become legitimated within the community of professional scientific practice and may even form identities of themselves as scientists. When this happens, a student’s practical epistemology of science (their own experiences with the construction of scientific knowledge) and their conceptions of how professional scientists construct knowledge may be equivalent. In order for this to be the case, a learner must have the self-perception that his or her own experiences

practicing science are in fact representative of professional science practices. It is the relationship between authenticity and formal and practical understandings of NOS that provides the theoretical basis for this study.

Figure 1-1 illustrates the theoretical framework for this study. In it, formal and practical understandings of NOS are disconnected from each other in inauthentic situations. However, as the authenticity of a science experience increases, these two constructs begin to overlap. In theory, in a highly canonically authentic context, a learner's understanding of formal NOS and practical NOS could be completely overlapping. These overlapping NOS ideas serve as the targets for investigation in this particular research study. This theoretical framework is important in that it legitimizes the use of NOS assessments designed to measure students' understanding of a formal NOS in an effort to measure students NOS ideas that are informed by both a practical and a formal understanding as potentially influenced by participation in the practices of professional science. It must be emphasized that the framework does not imply that in highly authentic situations in science, students' overlapping NOS ideas are necessarily informed. Rather, learner understandings can be naïve, informed or anywhere between. The framework does highlight that in canonically authentic situations, a learner's conceptions of a professional science, which once were "distal", may become as "proximal" as their personal epistemologies (Hogan, 2000).

Problem Statement

The above discussion establishes research apprenticeships as canonically authentic scientific contexts that are suitable settings for comparative investigations of the impacts of various approaches to influencing participant understandings of NOS. Such comparative investigations have yet to be conducted in these settings.

Additionally, there is very limited understanding of the role that reflection plays in influencing NOS understandings of participants in research apprenticeships. Other factors in addition to specifically designed pedagogical strategies for the teaching and learning of NOS in the context of research apprenticeships may influence participant conceptions of NOS, but these have yet to be specifically identified. The findings of this research study provide a deeper understanding of the answers to these problems.

Research Questions

Question 1

What are the impacts of various approaches (implicit approach, reflective approach and explicit/reflective approach) to NOS teaching and learning on participants' NOS ideas in the context of a research apprenticeship program?

Sub-question 1a

Do various approaches to NOS teaching and learning result in any significant changes in participants' NOS ideas during the experience?

Sub-question 1b

Are there significant differences in participants' changes in NOS ideas between participants experiencing different approaches to NOS teaching and learning?

Sub-question 1c

How are changes in NOS ideas different for participants experiencing different approaches to NOS teaching and learning?

Approaches to NOS Teaching and Learning

Research question one was intended to guide an investigation of three specific approaches to the teaching and learning of NOS in the context of a research apprenticeship. The three approaches are briefly operationalized below.

Implicit approach

In the implicit approach to NOS teaching and learning, no explicit instruction designed around individual NOS aspects is provided to the participant learners. Additionally, students do not encounter formal venues for reflecting on how their own experiences in authentic scientific inquiry are related to NOS. Students experiencing this approach in this study were participants in a seminar that was neither explicit nor reflective in regard to NOS.

Reflective approach

In a reflective approach to NOS teaching and learning, students are not explicitly introduced to individual NOS aspects. However, unlike in the implicit approach, these students are provided with structured opportunities to reflect on the ways in which their own participation within the practices of professional science relate to their understandings of knowledge generation within science. These reflections are individual rather than collaborative. The prompts guiding the reflective opportunities given in this study were constructed in ways that were general and did not explicitly reference individual NOS aspects. These structured reflective opportunities were provided to the participants in this study through a seminar that was not explicitly designed to introduce them to NOS aspects.

Explicit/reflective approach

In the context a research apprenticeship, an explicit/reflective approach to the teaching and learning of NOS involves instruction that has been explicitly designed to introduce students to consensus NOS aspects through a variety of activities and to subsequently provide opportunities for reflection. Participants experiencing this approach in this study reflected individually using the same journal prompts used in the

reflective approach. Additionally, the students were participating in collaborative reflective discussions linking activities to specific explicitly encountered NOS aspects. In this study, the explicit/reflective approach was conducted in the context of a seminar.

Question 2

How are participants' NOS ideas influenced by factors within their particular laboratory placements during a research apprenticeship program?

Sub-question 2a

What are the influencing factors that relate to changes in participants' NOS ideas?

Sub-question 2b

How are the influencing factors related to changes in participants' NOS ideas?

Rationale

These research questions were written based on the assumption that due to the canonically authentic nature of research apprenticeships any attempt to investigate learner conceptions of NOS would be simultaneously investigating learners' formal and practical epistemologies of science (Sandoval, 2005). Therefore the term "NOS ideas", as used in the theoretical framework, research questions and sub-questions, is referring to learners' overlapping conceptions of formal and practical NOS.

Question one and the sub-questions that follow are of particular importance to the science education community in that the results of a systematic comparison of various approaches to the teaching and learning of NOS in the context of a research apprenticeship program have yet to be published. Studies of the influence that research apprenticeships have on NOS understandings typically either examine an implicit approach or an explicit/reflective approach to the teaching and learning of NOS independently from one another (e.g. Bell et al., 2003; Schwartz et al., 2004).

Additionally, very few studies have examined the impact of reflection on secondary learners' conceptions of NOS (Barab & Hay, 2001; Wagner & Levin, 2007). For this reason the reflective approach was developed. The importance of this particular approach becomes clear in light of previous attempts to examine the impact of participation in research apprenticeship programs on learner conceptions of NOS through an implicit approach that have been inconclusive. In one research study in particular, which demonstrated that most participants' conceptions of NOS remained unaffected by an implicit approach, one participant did demonstrate gains in NOS understandings (Bell et al., 2003). The authors attribute these gains in NOS understandings to reflective opportunities that were provided to this learner by the mentor scientist. However, the role that reflection actually played was not systematically investigated.

It is important to recognize that factors in addition to specific pedagogical strategies for the teaching and learning of NOS may be influential in affecting student conceptions of NOS. Research question two and the sub-questions that follow drive an investigation of these factors. If research apprenticeships do impact student conceptions of NOS through an implicit approach, then an examination of this research question may reveal which aspects of the experience are influential in doing so. Previous research has identified collaboration within a community of scientific practice (Bleicher, 1996; Burgin, Sadler & Koroly, 2011; Richmond & Kurth, 1999), communication between the participant and his or her mentor (Bleicher, 1996; Ryder & Leach, 1999), interest in the research project (Burgin et al., 2011) and epistemic involvement in the formulation of research questions and methodological design (Ryder

& Leach, 1999) as possible factors that influence research apprenticeship participants' NOS ideas. It was expected that some of these factors might have been at play in this particular research apprenticeship and indeed, they were specifically looked for as research question two was investigated. However, an ethnographic approach to examining this research question left room for the identification of additional influential factors.

Additionally, an investigation of research question two and its sub-questions could have revealed the possible role of identity formation as an influencing factor within this research apprenticeship experience. Do student participants view themselves as legitimate members within a community of practicing scientists? On the other hand, do they perceive themselves to be outsiders who are just visiting the laboratory in which they have been placed? How do these feelings relate to the development of students' NOS ideas? The answers to questions like these could be used to place the participants in this study along the continuum of authenticity that is described by the theoretical framework and is represented in Figure 1-1. This would allow for claims regarding the amount of perceived overlap between participant's formal and practical NOS understandings and the role of this overlap on influencing change in participant NOS ideas.

Significance of Study

This study is significant in that the results obtained from it add greatly to current understandings of the relationship between participation in authentic scientific experiences like research apprenticeship programs and the development of sophisticated conceptions of NOS. A systematic comparison of various approaches to the teaching and learning of NOS had yet to be conducted in the setting of a research

apprenticeship program. Such a comparison had the potential to greatly inform the development of supplemental experiences within research apprenticeships similar to the one under investigation in this study in order to maximize their influence on participants' conceptions of NOS thereby impacting their scientific literacy. The results of this study also had the power to inform the understanding of the role that reflection plays in influencing NOS ideas. This study also had the potential to reveal specific factors of research apprenticeships that may impact participant NOS ideas. In addition to suggestions for the design of future research apprenticeships, the results of this study also were shown to have provided further rationale for the inclusion of increasingly authentic science activities in school settings in an effort to influence student NOS ideas.

Limitations of Study

One of the limitations of this study was the degree to which the various instructional approaches investigated through research question one could actually be controlled. For example, the degree to which reflection in and of itself explicitly influenced NOS understandings limited the design of the reflective approach and the efforts to investigate the impact of reflection apart from the impact of explicit attention to NOS aspects. In an effort to account for this limitation, reflective prompts for this group were carefully designed in ways that were general and did not explicitly instruct participants in regard to specific NOS aspects. Similarly, explicit NOS instruction can occur in a variety of settings and through unplanned naturally occurring discussions. There was no way to account for all interactions that took place between students, mentor scientists and seminar instructors during this experience. Although efforts were made to reasonably account for such explicit interaction through observations and

interviews, attributing gains in NOS to the impact of participation in scientific inquiry through an implicit approach was somewhat limited.

Additionally, this study was limited by the specific situated nature of the particular research apprenticeship that served as the context for this study. The participants in this study were highly motivated and successful learners of science and did not represent the broad sampling of students found in traditional secondary science school settings. As such, the findings have limited translation to all learners found within school science settings. Additionally, the support offered to students within a research apprenticeship (e.g. extended time, lack of formal assessment pressures, one on one mentorship, highly sophisticated and expensive laboratory equipment, etc.) was not typical of school science settings. Therefore the degree to which canonically authentic scientific inquiries of the nature that is described in this study can be implemented in school science settings is limited.

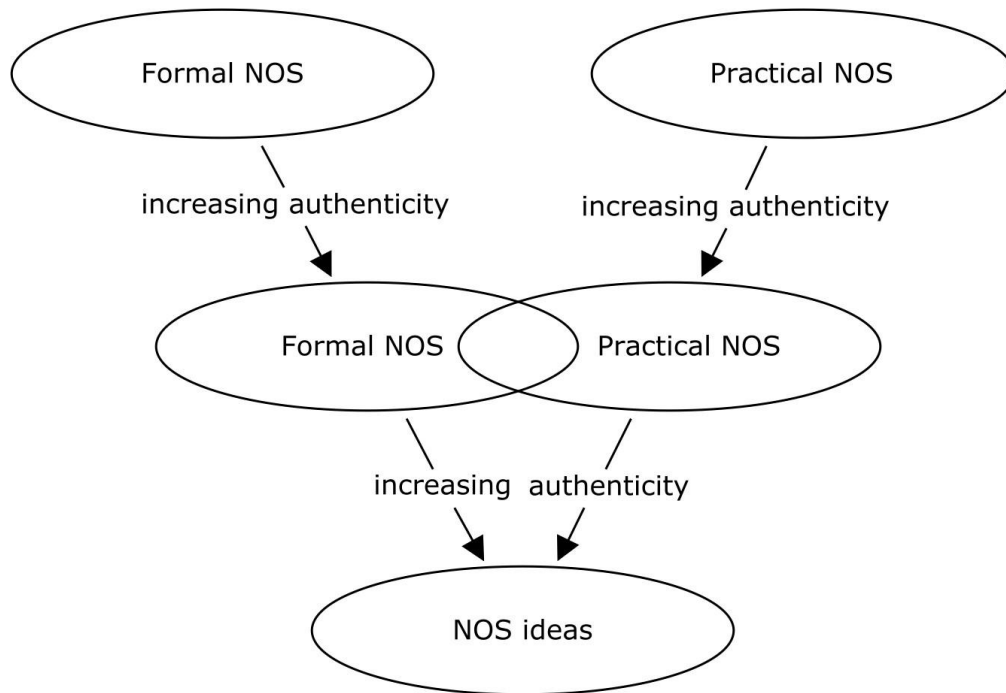


Figure 1-1. Theoretical Framework: The relationship between formal and practical nature of science (NOS) understandings as authenticity increases in science research experiences.

CHAPTER 2 LITERATURE REVIEW

Introduction

Research apprenticeships in science provide a uniquely authentic context for the investigation of the impacts of participation in professional science practices on a variety of desirable educational outcomes (Sadler et al. 2010). One of these investigated outcomes is the development of increasingly sophisticated Nature of Science (NOS) ideas among research apprenticeship participants (e.g. Bell et al., 2003; Richmond & Kurth, 1999; Schwartz et al., 2007). However, although science educators tend to agree that research apprenticeships can serve as appropriate contexts for influencing NOS ideas, their perspectives regarding how to best do so remain quite varied.

Part of this variance is due to differing assumptions made by researchers regarding the influence of participation by learners in scientific practices on the teaching and learning of NOS. Drawing from theoretical work regarding cognitive apprenticeships (Brown et al., 1989) and situated learning (Lave & Wenger, 1991), some science educators ascribe to the perspective that the processes involved in “doing” authentic science may result in the development of sophisticated NOS ideas among learners (e.g. Barab & Hay, 2001; Bleicher, 1996; Richmond & Kurth, 1999; Ritchie & Rigano, 1996; Ryder & Leach, 1999). This implicit view of the influence of research apprenticeships on NOS ideas is consistent with notions of science identity formation accompanying involvement in the discourses and practices of professional science (Gee, 1999; Gee, 2001). If students see themselves as involved and active members within the science community, then their ideas of knowledge development within science may be impacted.

Others have challenged the merits of such an implicit perspective of the teaching and learning of NOS ideas within research apprenticeships. These science educators suggest that in order to most effectively influence NOS understandings, NOS aspects must be explicitly addressed through designed curriculum intended to provide learners with experiences related to these aspects in addition to opportunities to reflect on them (e.g. Akerson et al., 2000; Schwartz et al., 2004). Science educators refer to this approach as the explicit/reflective approach to the teaching and learning of NOS (Lederman, 2007). The majority of research that supports the effectiveness of the explicit/reflective approach has been conducted in the context of traditional school settings (e.g. Akerson et al., 2000; Akerson & Volrich, 2006, Khishfe & Abd-El-Khalick, 2002; Yacoubian & BouJaoude, 2010). That being the case, the limited studies investigating the explicit/reflective approach in the context of research apprenticeships have demonstrated its effectiveness in these settings as well (Charney et al., 2007; Schwartz et al. 2004).

The empirical research base cited above regarding the merits of implicit and explicit/reflective approaches to NOS teaching and learning in the context of research apprenticeships has mixed results for a variety of reasons. Firstly, there exists conflicting evidence regarding the effectiveness of the implicit approach in research apprenticeships. For example, self-reported data indicate a positive impact on participants NOS ideas from an implicit approach (e.g. Barab & Hay, 2001; Bleicher, 1996; Richmond & Kurth, 1999; Ritchie & Rigano, 1996; Ryder & Leach, 1999), whereas data from open-ended validated questionnaires point towards no implicit relationship between participation in research apprenticeships and the development of

NOS ideas (Bell et al. 2003). Secondly, a majority of the empirical investigations of the explicit/reflective approach have been conducted in school settings with many fewer studies having been conducted in the context of a research apprenticeship program (Charney et al., 2007; Schwartz et al., 2004). Finally, every study that systematically compares the merits of the two approaches has been conducted in the context of school science rather than in the authentic context offered by a research apprenticeship (e.g. Bell et al., 2010; Khishfe & Abd-El-Khalick, 2002; Yacoubian & BouJaoude, 2010). This literature review will systematically examine the empirical research base cited above in greater detail. Figure 2-1 presents a concept map outlining the organization of this chapter.

The chapter begins with a discussion of research apprenticeships as canonically authentic experiences in science education. This section of the chapter will include an examination of the factors that make research apprenticeships uniquely authentic when compared to formal school science settings in addition to learner perceptions of outcomes associated with participation in such experiences. Next, attention will be turned to one of these reported outcomes, namely the development of sophisticated NOS ideas among research apprenticeship participants. This portion of the chapter will address definitions and conceptualizations of NOS along with ways to measure and assess learners' NOS ideas. The remainder of the chapter will focus on differing approaches to NOS teaching and learning in a variety of contexts and with multiple types of learners. This portion of the chapter is organized under the following three headings: (1) NOS in research apprenticeships, (2) NOS in school science and (3) studies comparing various approaches in school science settings. The second and third

headings in this portion, although not directly related to research apprenticeships as an educational context, become important components of the literature review in light of the relatively few studies of the explicit/reflective approach in authentic settings and the absence of studies that compare different approaches to NOS teaching and learning in apprenticeship programs.

Research Apprenticeships

Research apprenticeships are experiences in which learners participate in professional scientific practices under the supervision of a mentor in authentic contexts. These experiences are varied but they do share the following common traits: an experienced mentor scientist, a novice learner, a professional setting and a valuable and focused research project (Sadler et al., 2010). The mentor is typically a professional scientist (e.g. Barab & Hay, 2001) who is a faculty member of a university science department. Alternatively, this mentor may be a graduate student scientist working in a professional science laboratory (e.g. Bleicher, 1996; Burgin et al., 2011). Research apprenticeship programs have been designed for a variety of learners. These learners may be secondary students (e.g. Ritchie & Rigano, 1996), undergraduate students (e.g. Ryder & Leach, 1999), or preservice and/or inservice teachers (e.g. Schwartz et al., 2004). The professional setting may be in the field or it may be in a working science laboratory. The value and the focus of the research project are due to the collection of “real” scientific data used for a “real” scientific purpose (Barab & Hay, 2001). It is through the collection and interpretation of authentic data that the learner in the research apprenticeship participates in the practices of professional science.

Drawing from situated learning as a theoretical framework, research apprenticeships can be understood to be settings in which a learner moves along a

trajectory towards full participation in professional scientific practice through legitimate peripheral participation within a working scientific community (Lave & Wenger, 1991). It is this legitimate participation in professional scientific practice that results in classifying research apprenticeships as situations that provide learners with highly authentic experiences in science education.

Research Apprenticeships as Canonically Authentic Contexts

Before a full examination of the literature base reporting on the merits of participation in research apprenticeships, it is helpful to return to an examination of what makes these experiences uniquely authentic when compared to typical scientific inquiries conducted in school settings. When describing the authenticity of school science inquiry, a number of science educators make the argument that involvement in highly authentic science experiences will enable learners to experience cognitive processes, epistemological commitments and discourse practices that more closely resemble those experienced by working professional scientists as they construct scientific understandings (Chinn & Malhotra, 2002; Duschl & Osborne, 2002; Osborne, 2002; Roth, 1995). Buxton (2006) labels this point of view the canonical perspective of authenticity. It is not hard to see why, from this perspective, a scientific inquiry conducted in a formal school setting would likely be less authentic than one conducted in the non-formal professional science setting offered through a research apprenticeship. A formal setting is defined as one in which student participation is mandatory and traditional assessments (e.g. tests, quizzes, projects etc.) are the norm. In a non-formal setting student participation is voluntary and assessments tend to be more formative and non-traditional if present at all. Differing levels of authenticity in formal school science and non-formal research apprenticeships may be due to

differences in the nature of the mentor, curriculum design and institutional constraints present in formal and non-formal settings. Each of these differences will now be discussed in turn.

Mentor

In formal school settings, a classroom science teacher plays the role of a mentor to his or her students. This can be problematic when science teachers themselves tend to hold naïve understandings of NOS aspects (Herron, 1971; Abd-El-Khalick & BouJaoude, 1997). Herron's (1971) interview-based study of 50 inservice teachers revealed that they held an authoritarian perspective of NOS. Using questionnaires and follow-up interviews, Abd-El-Khalick and BouJaoude (1997) demonstrated that most of the twenty inservice Lebanese science teacher participants in their study thought that the scientific method was the only technique used by scientists to gather data.

In non-formal research apprenticeship settings, a scientist who is a working member within a scientific community of practice is mentoring the science learner. Although some scientists may have less than informed conceptions of NOS, it can be reasonably assumed that large numbers of scientists hold acceptable understandings of consensus NOS aspects (Osborne et al., 2003; Schwartz & Lederman, 2008; Wong & Hodson, 2009; Wong & Hodson, 2010).

Some have assumed that science teachers (mentors) who hold sophisticated understandings of NOS will be more likely to engage their students in experiences with higher levels of authenticity than will teachers with naïve understandings of the nature of scientific knowledge. Although there is some empirical evidence that supports this assumption (Bencze, Bowen & Alsop, 2006; Kang & Wallace, 2005), other science education researchers have conducted studies indicating that teacher NOS beliefs and

teacher practices are not necessarily correlated (Lederman, 1999; Lederman & Zeidler, 1987). Similarly, scientist mentors in the context of research apprenticeships who hold sophisticated understandings of NOS cannot be automatically expected to engage their apprentices in forms of inquiry that will necessarily impact their understandings of NOS.

There then is not much evidence to indicate that differences in NOS understandings between science teachers and professional scientists would result in any significant differences in mentorship quality. However, a factor that may contribute to the quality of mentorship provided by science teachers in formal school settings is the prior experiences of these teachers as participants in authentic science experiences themselves. Teachers who have had experiences in professional science may be more likely to engage their students in scientific inquiries that more closely resemble those of professional science. Windschitl (2003) examined the impact of six preservice science teachers' participation in an independent open-ended inquiry investigation on their enactment of authentic scientific inquiries in their practicum placements. Reflective writings, interviews & classroom observations revealed that the preservice teachers who had experiences participating in authentic scientific research either professionally or as undergraduate researchers were those that provided their students with opportunities to participate in authentic levels of scientific practice. Unfortunately, due to their only experiences in undergraduate science laboratories consisting of participation in highly scripted confirmatory activities, large numbers of traditional science teachers have not had opportunities to practice authentic science themselves (Trumbull & Kerr, 1993).

In contrast to this, mentors in non-formal research apprenticeships are typically working scientists who have had vast experiences practicing canonically authentic

professional scientific research (Sadler et al., 2010). Even when mentors in research apprenticeships are graduate students working in a professional science laboratory (Bleicher, 1996), they often have much more experience with canonically authentic science than does the typical school science teacher. These mentors may therefore be highly qualified to provide canonically authentic experiences to the science learners they are working with.

Curriculum design

In school science, the formal curriculum drives the instruction that takes place. Scientific inquiry that occurs in these settings is typically guided by designed laboratory activities present in textbooks or other curricular resources. Over the years, science educators have examined the levels of authenticity of the laboratory activities present in these curricula (Chinn & Malhotra, 2002; Germann et al., 1996; Herron, 1971).

Herron (1971) examined the Chemistry Education Materials Study curriculum, the Physical Science Study Committee physics curriculum, and the Blue Version Biological Science Curriculum Study in order to assess the levels of inquiry promoted within them. He found all three curricula to emphasize a form of inquiry that was nearly void of creativity. The majority of the laboratory activities present in these three curricula illustrated or demonstrated content that the students had previously encountered and did not involve any procedural design on the part of students. Herron classified these activities as “closed” in that the students merely followed procedural steps much like one follows the parts of a recipe in a cookbook.

Germann et al. (1996) analyzed 90 total laboratory activities from nine different biology science curricula all published in the late 1980s and early 1990s. They found that only three curricula attempted to engage the students in pre-laboratory activities,

that only two laboratory activities asked the students to pose a question, only 16 activities required the students to formulate a hypothesis and only one activity asked students to identify variables. Additionally, very few of these activities involved students in the design of investigations or the development of tables or charts to present their data. The laboratory activities also emphasized correct performance of laboratory skills and the obtaining of correct answers. Finally, very few of the laboratory activities offered opportunities for extension or application of results. The authors suggest that typical school science laboratory activities treat students like technicians rather than scientists.

Chinn and Malhotra (2002) examined 468 inquiry tasks in nine different upper elementary and middle school science textbooks. They found that only two percent of the inquiry activities required students to select their own variables when designing an investigation and that only four percent of the activities involved student development of simple controls for their investigation. It follows then from this and the previously cited studies that in order for science teachers (mentors) in formal school settings to promote high levels of inquiry in their classroom, they would have to make significant modifications to existing curricular resources or design scientific inquiry experiences themselves for their students.

In contrast, there is not typically a formal curriculum guiding the learning that takes place in non-formal settings such as research apprenticeships. In these experiences, the learner is engaged in participating in a genuine inquiry project that is serving a valuable purpose for his or her laboratory group (e.g. Barab & Hay, 2001). There is little chance that the apprentice is participating in scientific inquiry merely for the purpose of demonstrating agreed upon scientific theory or the transmittal of scientific “facts”.

Institutional constraints

In addition to teacher beliefs, teacher experiences and the formal curriculum, the institutional constraints within public school settings can also limit the levels of authenticity present. Bencze and Hodson (1993) suggest that time, public opinion and the emphasis on standardized testing all influence the levels of authenticity enacted in formal school settings. Hofstein and Lunetta (2004) discuss limits in resources, inflexible scheduling of laboratory facilities and large class sizes as additional institutional constraints to authenticity. In one report, Hume and Coll (2010) investigated the enactment of a new curriculum in New Zealand designed to promote high levels of authentic practice through scientific inquiry experiences in a classroom in which 11th grade students created and conducted an independent and original science investigation. The researchers observed that the intended curriculum did not necessarily match the actual curriculum experienced by the students due to a variety of external pressures faced by the teachers to emphasize and deliver certain content standards present on standardized assessments. These institutional constraints may have resulted in a misinformed perspective among students regarding the work of actual scientists. Similarly, science education researchers from Lebanon, Australia and Taiwan have discussed the negative effect that an emphasis on high-stakes standardized testing has on the implementation of authentic laboratory experiences in formal school settings (Abd-El-Khalick et al., 2004). Additionally, science education researchers in Israel have discussed the difficulty in implementing authentic experiences in school settings due to the long-term financial commitment and administrative support required (Abd-El-Khalick et al., 2004).

While there may be institutional constraints of a different nature within a research apprenticeship (e.g. the limited time of the program, desired levels of data quality, funding requirements, publication pressures), there is not the pressure to “teach to the test” that is so common in a traditional school setting. Therefore, the institutional constraints present during non-formal research apprenticeship experiences do not hinder authenticity to the same degree as do the constraints present in the schools where formal science education takes place.

Learner Perceptions of Research Apprenticeship Outcomes

Attention is now turned towards the outcomes associated with learner participation in research apprenticeship experiences specifically. The labeling of these outcomes comes from the recent literature review of research apprenticeships by Sadler et al. (2010). As discussed in that literature review, the majority of empirical evidence regarding these outcomes has come in the form of self-reported participant data. As such, all of the outcomes are primarily discussed in terms of learner perceptions of them. The first section deals with perceptions of science identity formation through participation in research apprenticeships. Outcomes of confidence, discourse practices and career aspirations are examined under this heading. The second section is organized around outcomes associated with the development of learner knowledge and skills in regard to science. These outcomes are scientific content knowledge, intellectual development, skills and NOS ideas. Since the focus of this study is on the development of NOS ideas through participation in research apprenticeships, a thorough discussion of this outcome will be reserved for subsequent sections of this literature review.

Science identity formation

The development of science identities within formal school settings has been documented as learners participate in project-based learning, partner with scientists through on-line work and are epistemically involved in the formulation of research questions and procedural decision making (O'Neill & Polman, 2004). If students in formal schooling situations come to see themselves as “little scientists”, then how much more so would learners in more highly authentic contexts such as research apprenticeships? Through research apprenticeships, participants perceive increased levels of confidence, participate in the discourse of professional science and report impacts on their science career aspirations. All of these outcomes result in or from the formation of science identities.

One of the reported outcomes of research apprenticeship programs is increased confidence to engage in scientific inquiry practices (Sadler et al., 2010). This outcome might be related to science identity formation within research apprenticeship programs. Stake and Mares (2001) utilized a pre/post questionnaire with 330 secondary student participants in a research apprenticeship program. The results of their study indicated no significant changes in student confidence, although the students self-reported such a change in their attitudes toward their abilities to do science. In a subsequent study, Stake and Mares (2005) utilized similar methods to investigate the influence of participation in research apprenticeships on secondary students' motivation and confidence in science. They found no immediate positive changes in these outcomes, but did find significant increases through follow-up surveys conducted three months after the research apprenticeship. The findings indicate that confidence in one's ability to do science continues to be affected following the completion of a research

apprenticeship experience. Increased confidence to do science could be related to self-identification as a productive contributing member of a scientific community involved in the production of scientific knowledge.

Similar identity changes associated with increased confidence have been seen in undergraduate participants of research apprenticeships. In interviews with 76 undergraduate participants of a summer research apprenticeship, 28% reported that as a result of their experience they were more able to think and work in ways that were similar to those of scientists (Seymour, Hunter, Larsen & Deantoni, 2004). Additionally, four percent of the students reported positive attitudinal changes in regard to their perceptions of themselves as researchers. A follow-up study was conducted in which these same students were interviewed two more times during their undergraduate careers (Hunter, Larsen & Seymour, 2007). The mentors of the students were also interviewed. Large numbers of both mentors and students reported on the professional growth of the participants as they became “scientists” through their experiences in research apprenticeships. The authors attribute this shift in identity to increased confidence among learners to participate in scientific research.

Participation in the discourse practices of a given culture is understood to be a component of identity formation (Gee, 1999). To become identified within a certain community, a person needs to culturally act like an authentic member of that group. Included in the actions of a community are the forms of communication that are the norm for its members. In science, discourse practices include very specific forms of argumentation including a prioritizing of empirical evidence when making claims, engagement in collaborative discussions with other members within the scientific

community and the use of technical vocabulary in addition to other factors (Duschl & Osborne, 2002). In summary, when a learner of science begins to communicate like a scientist, he or she begins to form a science identity.

The acquisition of professional science “discourse practices” is an empirically reported outcome of participation in research apprenticeships (Sadler et al., 2010). This outcome is most notably observed in research apprenticeship programs designed for secondary learners (Barab & Hay, 2001; Bleicher, 1996; Charney et al., 2007; Richmond & Kurth, 1999).

Some of the empirical research describes the use of scientific discourse in the formulation of arguments based on empirical evidence. In their naturalistic study of 24 middle school students who participated in a two-week research apprenticeship, Barab and Hay (2001) document through transcripts of group discussions the participants engaging in scientific discourse practices. This was primarily observed through group debates. In these debates, students presented explanations, defended their positions with examples from the data they had collected, revised their explanations based on other examples given to them by their peers and ultimately further developed their hypotheses as a result. This process of communication that impacted laboratory practices very closely mirrors the discourse practices of professional scientists. Similarly, Charney et al. (2007), in a case study of two high school student participants of a research apprenticeship, report that one of the students “framed logical arguments and interpreted these arguments to explain the linkage between experimental results and prevailing theory” (p. 209) in her reflective journal entries throughout the experience.

Other studies describe the influences of using technical scientific vocabulary on the formation of science identities. Bleicher (1996) reports on a case study of one high school student participant of a six-week research apprenticeship program who developed professional discourse practices similar to those of his mentors (three different graduate student scientists) during the experience. The language and communication style of these mentors was evidenced in the student's research presentation. In this report, Bleicher (1996) discusses language as a "tool" that was part of the culture of professional practice in the science laboratory in which the student was embedded. As such, the student developed skills in using the tools of professional science through his research apprenticeship experience. Likewise, Richmond & Kurth (1999) discuss the development of increasingly complex uses of technical language as a scientific tool over the course of high school student participation in a seven-week research apprenticeship program through an analysis of student writing and talk. When discussing technical language used by participants, the authors write, "they began to understand the role that this particular kind of communication plays in clarification and construction, that the discourse of science is part of the practice of science" (Richmond & Kurth, 1999, p. 682). The authors describe the use of scientific discourse as one of the resources that students used as they formed identities within the culture of professional science.

Another reported outcome of participation in research apprenticeships is the development of career aspirations related to science (Sadler et al., 2010). This outcome is discussed here under the heading "identity formation" because the development of positive science identities may result in an increased desire to continue participating in

the culture of science beyond the experience of the research apprenticeship. Included in the discussion of career aspirations are decisions made by participants to enroll in graduate degree programs. An examination of this outcome is present in studies reporting on the impacts of research apprenticeships designed for secondary students (Abraham, 2002; Burgin et al., 2011; Cooley & Bassett, 1961; Davis, 1999; Roberts & Wassersug, 2008; Stake & Mares, 2001) and for undergraduate students (Hackett, Croissant & Schneider, 1992; Hunter et al., 2007; Seymour et al., 2004).

The studies focusing on secondary student participants in research apprenticeships specifically address issues related to career aspirations. Three discuss an increased desire by students to pursue science related careers, particularly those involving research (Abraham, 2002; Cooley & Bassett, 1961; Davis, 1999). That this increased desire is evidenced by minority students who are underrepresented in science careers is an encouraging finding (Davis, 1999). Roberts and Wassersug (2008) conducted a retrospective study that revealed a significant correlation between participation in a research apprenticeship as a secondary student and entering and maintaining a career in science. The same correlation was not evident in students who participated in authentic research for the first time as undergraduates. Such findings speak to a powerful impact of research apprenticeship experiences for secondary students on influencing their career decisions. In another study, the career aspirations of secondary students are observed to shift away from medical related careers and toward other careers in science (Stake & Mares, 2001). One recent study reports that firm career aspirations (either toward or against science) among secondary student participants of research apprenticeships remain uninfluenced by their experience as

self-reported in student interviews. However, students with a general level of interest in pursuing a science related career report that their experience refined and narrowed their interest (Burgin et al., 2011).

Studies examining research apprenticeships designed for undergraduate students report that participants leave with an increased desire to attend graduate school in pursuit of a science related career (Hackett et al., 1992; Hunter et al., 2007; Seymour et al., 2004). Like programs for secondary students (Burgin et al., 2011; Stake & Mares, 2001), apprenticeships for undergraduate students also play a role in specifying vague science career aspirations (Hunter et al., 2007; Seymour et al., 2004).

In summary, research apprenticeship experiences play a direct role in influencing the development of science identities among learner participants. This is evidenced in an increased confidence to participate in the practices of professional science including the normal forms of scientific discourse. This self-perceived identity formation within science may result in science career aspirations among secondary learners and undergraduate participants in research apprenticeships.

Development of knowledge and skills

Accompanying the formation of science identities through research apprenticeships is the development of the knowledge and skills necessary to participate in authentic scientific practices. Again drawing from the work of Sadler et al. (2010) to identify outcomes of participation in research apprenticeships, the outcomes of scientific content knowledge, intellectual development, skills and NOS are discussed in this section.

The development of scientific content knowledge is an often self-reported outcome given by participants of research apprenticeships (Abraham, 2002; Brown & Melear,

2007; Burgin et al., 2011; Grindstaff & Richmond, 2008; Raphael, Tobias & Greenberg, 1999; Seymour et al., 2004). These participants include representative populations of secondary students, undergraduate students and teachers that participate in these types of experiences. The Grindstaff and Richmond (2008) article discusses the self-perceived role of student collaboration in the social construction of conceptual understanding. In a few of these studies, including a companion piece to the Seymour et al. (2004) study, the researchers utilized follow-up interviews with mentor scientists to corroborate the self-reported data (Burgin et al., 2011; Hunter et al., 2007). The Burgin et al. (2011) piece is unique in that concept mapping by secondary student participants was also used to corroborate the self-reported gains in understanding of scientific content knowledge. In this study, the concept maps generated by learners were observed to increase in complexity and in the number of discipline specific conceptual constructs over the course of a summer research apprenticeship program.

Researchers in other studies have sought to examine the accuracy of conceptual understanding revealed in student interview responses and student presentations given at the end of a research apprenticeship experience (Bleicher, 1996; Ritchie & Rigano, 1996). Ritchie & Rigano (1996) interviewed two secondary student research apprenticeship participants. The researchers specifically asked them questions about scientific content and analyzed their responses for accuracy. They were convinced that these participants developed sophisticated conceptual understanding of chemistry that would not have developed in more traditional educational contexts. "We were satisfied that both students were progressively grasping a range of chemical concepts beyond their school experience" (p. 807). In contrast to the results of this study, analysis of a

secondary learner's final research presentation revealed a less than ideal conceptual understanding of his topic as a result of his apprenticeship experience (Bleicher, 1996).

Very few studies rely on direct assessments of scientific content knowledge when making claims about resulting conceptual understanding from participation in research apprenticeships (Sadler et al., 2010). In one study that did rely on a direct assessment, researchers utilized open-ended Advanced Placement biology test questions to examine the conceptual understanding of 30 secondary students participating in an apprenticeship program (Charney et al., 2007). Comparison of responses to the questions given at the beginning and then again at the end of the experience revealed that students' conceptual understandings of molecular genetics increased significantly over the course of the program.

In addition to conceptual understanding, another related outcome is the intellectual development of research apprenticeship participants (Sadler et al., 2010). This construct deals with scientific reasoning and critical thinking skills of science learners. Such outcomes are reported for secondary students (Cooley & Bassett, 1961; Hay & Barab, 2001), as well as undergraduate students (Seymour et al., 2004; Hunter et al., 2007). Although much of this research relies on student self-reported data (Seymour et al., 2004; Hunter et al., 2007), the work by Cooley & Bassett (1961) utilizes standardized tests of scientific thinking to examine the intellectual development of secondary student participants in an apprenticeship experience. By comparing pre and post-test scores, the authors describe significant gains made by students in the use of hypotheses, the interpretation of data and quantitative reasoning skills.

The intellectual development of participants in research apprenticeship programs has been linked to epistemic involvement (Hay & Barab, 2001; Ryder & Leach, 1999). In a comparison study of an apprenticeship experience and a “constructionist” experience for secondary learners, Hay and Barab (2001) document no critical or creative thinking among participants in the apprenticeship experience. They attribute this to the fact that students in the apprenticeship were assigned their project and were uninvolved in its design due to the limited timeframe (two weeks) of the experience. Similarly, Ryder and Leach (1999) report that undergraduate students who were involved in the formation of research questions showed gains in scientific reasoning, whereas students who were merely collecting data through the enactment of previously established procedures did not.

Additionally, many participants of research apprenticeships perceive that through their experiences they have gained skills that enable them to participate meaningfully in authentic scientific research (Sadler et al., 2010). These skills include an ability to be involved in the research process through the formulation of research questions and the designing of procedures (Seymour et al., 2004), communication skills (Hunter et al., 2007, Seymour et al., 2004) and technical skills such as the manipulation of laboratory equipment (Ritchie & Rigano, 1996; Seymour et al., 2004).

Finally, the development of sophisticated understandings of NOS is an outcome from participation in research apprenticeships that is reported in the empirical literature (Sadler et al., 2010). Since the focus of this present study is on the development of NOS ideas in these contexts, the remainder of the literature review will be devoted to exploring this outcome.

In summary, participation in research apprenticeships results in many participant-perceived outcomes. These outcomes include the formation of science identities and the development of understandings and skills. The formation of science identities includes outcomes of confidence and discourse practices which result in science career aspirations. The development of understandings and skills includes the outcomes of scientific content knowledge, intellectual development and skills (participation in the research process, communication and technical skills) in addition to the development of NOS ideas. This last outcome will now be explored in depth.

Nature of Science (NOS)

As was discussed in Chapter 1, NOS has been defined as “the values and assumptions inherent to the development of scientific knowledge” (Lederman & Zeidler, 1987, p. 721). This is the definition that is used in this study. Before an examination of the various approaches to NOS teaching and learning in different educational contexts, it is helpful to briefly reexamine a conceptualization of various aspects of NOS in addition to methods of assessing NOS and strategies for the teaching and learning of NOS.

NOS Conceptualized

In Chapter 1, descriptions were made of various efforts to compile consensus lists of component NOS aspects by science educators (Lederman et al., 2002; Osborne et al., 2003; Sandoval, 2005; Schwartz & Lederman, 2008). Although some have questioned the existence of consensus aspects (Alters, 1997), most science educators would agree that at least at a fundamental level, common understandings of NOS aspects that are philosophically relevant to K-12 science education can be expected to

be agreed upon by all stake-holders in science education (Lederman, 2007; Smith et al., 1997).

Lederman et al. (2002) identify seven of these consensus NOS aspects in their description of the development of an open-ended questionnaire used to assess them. These aspects are (1) the empirical nature of scientific knowledge, (2) the distinctions and relationships among scientific theories and laws, (3) the creative and imaginative nature of scientific knowledge, (4) the theory-laden nature of scientific knowledge, (5) the social and cultural embeddedness of scientific knowledge, (6) the myth of the scientific method and (7) the tentative nature of scientific knowledge. Sandoval (2005) has condensed these seven consensus aspects into the following four NOS constructs: (1) the construction of scientific knowledge, (2) the diversity of scientific methods, (3) the different forms of scientific knowledge (including hypotheses, models, theories and laws) and (4) that scientific knowledge varies in certainty. Sandoval's list was used to organize the discussion of scientific epistemologies in the reform document *Taking Science to School* (NRC, 2007). In this light, discussions of gains in NOS understandings reported in this literature review will be framed in terms of Sandoval's (2005) four aspects of NOS. When authors report gains in understandings of NOS aspects in terms of other consensus lists, efforts will be made to interpret these descriptions from the perspective of Sandoval's (2005) framework.

It is also helpful to remember that some science educators believe that NOS understandings are highly situational and that science learners may hold multiple NOS conceptions simultaneously (Hogan, 2000; Sandoval, 2005). Hogan (2000) argues that students hold proximal NOS understandings related to their own experiences in the

generation of scientific knowledge and distal NOS understandings of the generation of scientific knowledge by professional scientists. Sandoval (2005) labels these as practical and formal epistemologies of science respectively. The theoretical perspective guiding this current research study is that learners' practical and formal epistemologies of science overlap in the context of canonically authentic science experiences and that this overlapping nature has direct consequences for the teaching, learning and assessment of NOS ideas.

Measurement/Assessment of NOS

Understandings of how to best assess learner conceptions of NOS have developed over time. Some of the earliest tools used to measure NOS ideas relied on quantitative scoring of multiple choice questions and responses on Likert-scale surveys (Cooley & Klopfer, 1963; Rubba & Anderson, 1978). In more recent years, science educators have questioned the merits of relying on the forced responses obtained through such traditional instruments to assess NOS ideas (Lederman et al., 1998). As such, open-ended questionnaires with follow-up interview protocols have been developed in order to allow students to provide their own NOS perspectives and give elaborate descriptions of those ideas. The most widely used open-ended NOS questionnaire among science educators is the Views of the Nature of Science Questionnaire (VNOS) (Lederman et al., 2002). Recently, science education researchers like Sandoval (2005) have called for a more ethnographic approach to the investigation NOS ideas based on observations of actual student practice in authentic science contexts.

Approaches to NOS Teaching and Learning

There are two main approaches to NOS teaching and learning that are described by science educators. The first of these is the implicit approach. According to this perspective, the NOS ideas of science learners will be impacted by implicit messages carried through participation in science practice. The second approach is the explicit/reflective approach. Advocates for the explicit/reflective approach argue that learners of science should explicitly encounter target NOS aspects and have opportunities to reflect on how these NOS aspects relate to their own involvement in the construction of scientific knowledge. The authors of one study give a clear definition of the explicit/reflective approach. “This approach intentionally draws learners’ attention to aspects of NOS through discussion, guided reflection, and specific questioning in the context of activities, investigations, and historical examples” (Schwartz et al., 2004, p. 614). For the purposes of this literature review, the explicit/reflective approach will be discussed as the explicit approach. As will be seen in the empirical literature, this is due to the variety of uses of the term “reflection”. Some explicit approaches involve no reflective opportunities, and some implicit approaches actually do involve some form of reflection even if NOS aspects are not explicitly addressed.

The approaches to NOS teaching and learning reported in the literature base are discussed in three sections. The first is a treatment of the teaching and learning of NOS in the context of research apprenticeships. The majority of the studies in this section apply an implicit approach to NOS teaching and learning. The second section examines NOS teaching and learning in traditional school settings. In these contexts, an explicit approach is the predominant approach. This section is included in order to give a thorough treatment of the merits of explicit approaches as this approach has been

seldom used in research apprenticeship settings. Finally, a third section discusses studies that compare various approaches to the teaching and learning of NOS ideas. All of the studies examined in this section are conducted in the context of formal school science. They are included in this literature review because no similar studies have been conducted in the context of research apprenticeship programs.

NOS in Research Apprenticeships

Twenty-one studies that investigated participation in research apprenticeships as a context for influencing learner NOS ideas are discussed in this section. Table 2-1 summarizes these studies on the basis of the approach to NOS teaching and learning that was employed, the methods used to assess participant NOS ideas, and the results in terms of Sandoval's (2005) four aspects of science epistemology. Only three of these studies took an explicit approach to teaching and learning and only six of them had a reflective component to their approach. The studies are presented in the table in the order that they are discussed in this section.

Implicit Approaches to NOS Teaching and Learning in Research Apprenticeships

Given the predominance of the implicit approach to the teaching and learning of NOS in the context of research apprenticeships, a discussion of studies reporting on the merits of this approach is a logical place to begin this section. Studies that investigated the impact of participation in the practices of authentic science on student's conceptions of the nature of scientific knowledge construction without systematically and explicitly addressing various NOS aspects were classified as utilizing an implicit approach. Eighteen of the studies described in Table 2-1 fall under the implicit approach label. These studies investigate the assumption made by many science educators and stakeholders in science education that students will develop sophisticated

understandings of NOS as a result of “doing” science (Lederman, 2007). First, studies reporting gains in learner NOS ideas as a result of an implicit approach are described. Next, studies that describe limited or no gains in learner NOS ideas are examined. The studies in these two sections are organized based on the academic level of the reported population.

Gains from implicit approaches in research apprenticeships

Secondary students. A number of studies report and discuss gains in NOS ideas held by secondary learners as a result of their participation in research apprenticeships as a result of an implicit approach (Barab & Hay, 2001; Bleicher, 1996; Burgin et al., 2011; Cooley & Bassett, 1961; Richmond & Kurth, 1999; Ritchie & Rigano, 1996). Cooley and Bassett (1961) investigated the influence of a summer science and mathematics institute for gifted secondary learners on a number of desirable outcomes including NOS ideas. The participants in this study were fifty-five high school juniors. The research apprenticeship experience consisted of two weeks of intense study of advanced topics in science and math followed by eight weeks of authentic research with professional scientists in their laboratories. The authors utilized a pre-post design to make claims about changes in student understanding of NOS over the course of the program. Student participants took a standardized instrument, the Facts About Science Test, at the beginning and the end of the program. This assessment consisted of a number of multiple-choice questions. One of these questions is presented below.

34. Of the following, which is the most important characteristic of science?
- A. As many facts as possible are acquired and classified.
 - B. Statements are not made unless absolutely true.
 - C. Its own mistakes are discovered and corrected. (Cooley & Bassett, 1961, p. 212).

The desired response to this item was choice (C).

Comparisons of the average pre and post-experience scores on this instrument were made and a statistically significant p value resulted from t-tests of learner change. The authors expected these results because in this program “student exposure to scientists in action [was] the primary activity” and students were given “a close look at scientific research, both the menial tasks and the thrill of discovery” (Cooley & Bassett, 1961, p. 211). In other words, students were given the opportunity through the program to participate in science research and the authors expected that such an experience would influence their understandings of science as an enterprise and the methods chosen for this study revealed that it did so.

The Cooley and Bassett (1961) study provides an illustrative example for discussing some of the inherent problems with traditional standardized NOS assessments. In this study, student responses to multiple-choice questions were the only data analyzed to make claims about changes in NOS understandings. One of the main critiques of assessments like the one used in this study is that they do not allow for freedom of expression, but rather force students into responses which are then analyzed according to the perspectives of the authors of the assessments (Lederman et al., 1998). Looking at the example question provided above, it is apparent that at the time of this study, a sophisticated understanding of NOS was believed by science educators to involve the conception that knowledge formation in science was a process of discovery and that correction of mistakes would ultimately reveal the “true” reality of nature. In fact, when discussing the positive “gains” made by secondary student participants, the authors say, “the trends in their image of science and scientists were, in general, toward increased realism” (Cooley & Bassett, 1961, p. 211). This conception

of “realism” is no longer understood to be a sophisticated understanding of NOS, but rather a quite naïve one (Lederman, 2007). Given that students were not provided with any opportunity to express a perspective of science other than one informed by the “realism” that guided the authors of the standardized multiple-choice test used in this study, it is hard to make any definitive claims about the impacts of participation in this research apprenticeship program on participant conceptions of NOS ideas through an implicit approach.

Other studies use student self-reported data to make claims about the impacts of research apprenticeship participation on learner NOS conceptions resulting from an implicit approach. For example, Bleicher (1996) conducted a case study of a single high school student participant in a research apprenticeship in order to examine the social and cultural aspects of laboratory work that influenced the student’s participation in the program. The context for this study was a six-week summer research apprenticeship experience designed for 11th grade students. Students worked as apprentices to graduate student mentors who were directly supervised by a science faculty member of a research university. Research centered on material-science topics related to the development of electronic devices. In addition to the laboratory research component of the experience, students participated in seminars, attended meetings and kept personal journals. The authors describe these seminars as being designed to “familiarize them [research apprenticeship participants] with methods of scientific presentation and discourse” (Bleicher, 1996, p. 1119). Students gave a public presentation of their findings at the end of the research apprenticeship. Although students participated in seminars and reflected in journals, the authors do not clearly articulate the instructional

objectives guiding these reflective activities or the specific topics that were addressed. As such, this approach has been classified as implicit rather than explicit. Another reason for this is that the author does not attribute gains in NOS ideas to the topics presented in these seminars but rather to the impact of participation in a working laboratory research group. Primary sources of data from this observational study were field notes, video recordings, interviews and participant journal entries. The field notes and video recordings were used to make claims about the participant's NOS ideas.

Through observation of laboratory group meetings, Bleicher (1996) documents that the group members who were mentoring the secondary student in this case study placed value in the “simplicity of design” and the “cleverness in methodology” of scientific research (p.1123). Bleicher (1996) continues to say that through recorded conversations in these laboratory group meetings in regard to how to interpret graphical representations of data, “one got the impression that this same group later in time or another group of researchers might come up with a different interpretation of the same data” (p. 1123). It was clear to the researcher then that these mentors held sophisticated understandings of the construction of scientific knowledge and that scientific knowledge varies in certainty. What is most intriguing about this study is that Bleicher (1996) then says, “after the first group meeting, [the case study participant] began to model the group's views, values, and even ways of talking about aspects of designing and performing experiments” (p. 1123). It follows that the secondary student participant acquired the sophisticated NOS ideas of his mentors through participation in laboratory group meetings that were part of the culture of the lab in which he was placed.

Ritchie and Rigano (1996) similarly document the impact of participation in research apprenticeships in science on participants' NOS ideas resulting from an implicit approach. Their study is a case study of two secondary students (11th and 12th grade) who were participating in an intense research apprenticeship program in Australia. This program lasted over six months during which the participants were released from school one afternoon per week to work on research in the laboratory of a mentor scientist. The two students in this program were investigating research in the field of chemical engineering. The primary sources of data for this observational study were field notes and subsequent participant interviews.

The authors describe gains in NOS ideas that accompanied participation in this research apprenticeship. The NOS gains reported in this study relate to understandings of the construction of scientific knowledge and that scientific knowledge varies in certainty. Specifically, the students were observed and reported in interviews that they became "empowered to take responsibility for their own actions by seeking the warrants for the viability of their knowledge claims" (Ritchie & Rigano, 1996, p. 813). This reveals how students came to understand the empirical nature of scientific knowledge. The student participants in this study described a tendency to "fudge" the data in school science laboratory activities in order to present correct answers to their instructor. In contrast to this, these students came to understand the persistence of professional scientists as they accounted for and faithfully reported unexpected results. This notion is related to understandings of how scientific knowledge varies in certainty. The authors state that these students learned "to appreciate that scientific practice deals with uncertainty and adaptability" (Ritchie & Rigano, 1996, p. 805). Participant gains in NOS

ideas are linked to their increasing ownership over the project that occurred during the experience.

In another study demonstrating the merits of the implicit approach in these contexts, Richmond and Kurth (1999) describe the development of the views of scientific practice and culture held by seven 11th and 12th grade students over the course of their participation in an apprenticeship program. The program under investigation was a seven-week residential summer apprenticeship. The authors state that in addition to the science research activities in their mentor's laboratory, students regularly reflected through journal writing activities and discussions on their understandings of science, scientists, prior science experiences and science careers. However, the exact nature and frequency of the reflective prompts is not described in this study. Although these prompts may have provided explicit NOS instruction, without further information, this experience is classified as using an implicit approach with a reflective component. The participants in this study were interviewed three times during the apprenticeship. Primary sources of data include these interviews in addition to student journal entries.

The authors report that the student participants demonstrated gains in understanding of four aspects of the culture and practice of science. These were technical language, collaboration, uncertainty and inquiry. The aspects of collaboration and uncertainty are relevant to understandings of the construction of scientific knowledge and that scientific knowledge varies in certainty. Prior to their experience, these student participants held the perspective that scientists work in isolation on their

research projects. The actual collaborative nature of their individual laboratory placements modified this conception. In the words of one participant:

When you're at school, you think that a scientist is living up in a cave, in his own little lab. Nobody else is there, and he's just going mad, like Frankenstein. Mad scientist, you know? And being here...you learn it's not like that. It's just an office, where everybody is in there together, everybody's helping each other...(Richmond & Kurth, 1999, p. 684)

The students also developed understandings of the uncertainty that is inherent to scientific knowledge. In their school science experiences, the students were familiar with following given procedures to achieve definite results that were often known ahead of time. One student spoke of the doubt that accompanied this uncertainty:

I think it's important to have that sort of doubt, but also the confidence in what you've done, and what you've looked at and what you've determined...it's more interpretation that doesn't have an answer key. And I think that's good...(Richmond & Kurth, 1999, p. 686)

Although the authors use quotes like that above to make an overall claim about the gains in participant understandings of the uncertainty of scientific knowledge, they also acknowledge that this understanding was not complete. Some of the participants still held on to the belief that uncertain and unexpected results were the products of mistakes on the part of the researcher.

The authors of this study attribute gains in understandings of these NOS ideas primarily to the actions and interactions of these students in various communities of cultural practice (Richmond & Kurth, 1999). These students came to develop sophisticated understandings of the epistemologies of scientific knowledge through legitimate membership within their laboratory groups according to the authors of this report. That being said, the authors do discuss to a more limited degree the role that the aspects of the program outside of the laboratory played in influencing these

understandings. They mention how activities such as watching a movie or listening to a guest speaker prompted reflective discussions that influenced the ways in which the participants were writing and talking about the practices of science in their journals and interviews. In summary, student understandings of NOS were influenced through both implicit approaches and through reflective opportunities through discussions and journaling.

Other studies have investigated the impacts of an implicit approach with an added reflective component. Barab and Hay (2001) investigated the impact of an apprenticeship program designed for middle school students. The experience under examination was a two-week apprenticeship in which middle school students and middle school science teachers worked with research scientists at a university on scientific research projects covering a wide-range of science topics. Through the experience, each group also developed and gave a presentation of the results of their research. Reflection was also a major component of this experience. In fact, Barab and Hay, in their description of why “participatory science learning” like research apprenticeships is unique from “formal schooling”, reference Schön (1987) when emphasizing the importance of both reflection-in-action and reflection-on-action during research apprenticeship experiences. Students in this experience kept an electronic notebook, in which they held online discussions with mentor scientists and other students in the program, received background information from scientists, were informed of the schedule of the program and recorded their data and reflections from their laboratory work. The reflective journal did not provide for explicit examination of NOS topics.

Twenty-four middle school students served as the population for this study. Part of the uniqueness of this study is the varying socioeconomic backgrounds and academic levels of these participants (Barab & Hay, 2001). This is because most apprenticeship programs are designed for gifted and highly motivated science students (Sadler et al., 2010). These students were working in groups of four with one middle school teacher and one mentor scientist. Sources of data included interviews, field notes, videotapes of learner participation and electronic journal entries.

The authors of this study truly believe that participation in the practices of professional science influenced understandings of the construction of knowledge within of science. “One of the real benefits of [the research apprenticeship program] was that there was no separation between doing science and learning science, both occurred simultaneously with practices informing learning and learning informing practices” (Barab & Hay, 2001, p. 84). As a result of practicing science, participants held discussions with their mentors about the construction of scientific knowledge. The authors point out that these conversations were not planned lectures by mentors, but rather were discussions initiated by student participants and as such were a direct result of doing science. The conversations involved discussions of unexpected results in science amongst other topics. Additionally, student participants held debates with each other about the meaning of their results.

These types of discussions, present in all of the groups participating in [the research apprenticeship program], suggest that the participants (to some extent) had opportunities to participate in the social negotiation of meaning, a practice that is fundamental to doing science. (Barab & Hay, 2001, p. 89)

The authors continue to say that through participation in the social negotiation of meaning, “many participants were able to gain an appreciation of the situated nature of

science” (Barab & Hay, 2001, p. 96). The students came to understand that science is very complex, that unexpected results are the norm and that the meaning of results is determined through social discussions among scientists.

One recent study adds to the discussion of the impacts of participation in research apprenticeships relying on implicit approaches in that it attempts to make links between aspects of the experience that are directly related to gains in NOS understandings (Burgin et al., 2011). In this interview-based study, eighteen 11th and 12th grade students participated in a seven-week summer residential research apprenticeship program at a large university. The study revealed that some of the participants exhibited gains in their understandings of the construction of scientific knowledge and that scientific knowledge varies in certainty. It was demonstrated that students’ interest in their project and the degree of collaboration that they experienced in their laboratory placement might have been positively linked to gains in NOS understandings. Epistemic involvement (the degree to which students took part in the development of their project) was not linked to the development of sophisticated NOS ideas.

There is then some empirical evidence that secondary student participation in research apprenticeship experiences utilizing an implicit approach results in gains in understandings of NOS (Barab & Hay, 2001; Bleicher, 1996; Burgin et al., 2011; Cooley & Bassett, 1961; Richmond & Kurth, 1999; Ritchie & Rigano, 1996). One study that reports gains in understandings of NOS for secondary students utilizes an outdated assessment instrument that measures conceptions of NOS that are no longer agreed upon by the science education community (Cooley & Bassett, 1961). The remaining studies utilize observations and interviews to allow students to express their own

perspectives in regard to their NOS ideas. However, none of them use a validated instrument such as the views of the nature of science questionnaire (Lederman et al., 2002) to specifically target student ideas of certain NOS aspects. Therefore the findings of these studies are limited to NOS aspects that are self-reported by students or specifically observed in their laboratory practice.

Undergraduate students. A handful of studies report on the positive impact of undergraduate involvement in authentic scientific research experiences through apprenticeship opportunities utilizing implicit approaches (Ryder & Leach, 1999; Sabatini, 1997). Sabatini (1997) reports on the impact of an undergraduate research apprenticeship experience where students work on issues related to ground-water remediation. A focus-group “brainstorming session” was held with four undergraduate students who were participating in the apprenticeship program in order to allow them to self-report the educational value of the experience. A few of the self-reported advantages and benefits of the experience are relevant to this discussion of the development of NOS ideas. One of these is that the “assumption/limitations of ‘standard’ methods-laws etc. become apparent” (Sabatini, 1997, p. 3). Related to this, the students said that the research apprenticeship provided a “valuable experience in problem solving- creative and imaginative approaches” (Sabatini, 1997, p. 3). Finally, the students reported that, “camaraderie developed with the mentor and other students” (Sabatini, 1997, p. 3). Based on these statements, the undergraduate students believed that their understandings of the forms of scientific knowledge, the diversity of scientific methods and the construction of scientific knowledge had all been impacted as a result of their involvement in an authentic research apprenticeship.

Ryder and Leach (1999) similarly explored undergraduate student conceptions of images of science generated through participation in a one year research apprenticeship that utilized an implicit approach to NOS teaching and learning. Eleven undergraduate students participated in the study. The students worked on open-ended scientific research projects in a variety of science disciplines under the supervision of mentor scientists. Primary sources of data were interviews with both the students and their mentors. Students were interviewed both at the beginning and the end of their experience. Questions asked of the students included the following: “Why do scientists do experiments?”, “Why do you think that some scientific work stands the test of time whilst other scientific work is forgotten?” and “How are conflicts of ideas resolved in the scientific community?” (Ryder & Leach, 1999, p. 948).

In analyzing the responses to these questions, the authors identify one student whose naïve view of NOS limited the influence of her project on her understandings of NOS. The authors say that this student’s perspective on NOS was “data-driven” and that she was unable to cope with the epistemic involvement required of her as the project progressed. Of the other ten students, eight of them experienced a level of epistemic involvement that the authors believe promoted sophisticated NOS ideas. As an example, for one of these students, “reading professional research articles developed his view that more than one interpretation can legitimately be applied to a single set of data” (Ryder & Leach, 1999, p. 952). Other students developed the ideas that “dedication and determination are needed in science” and that “science is a human activity” (Ryder & Leach, 1999, p. 952). For still another student the “interactive aspect of her project work [was] a major influence on her images of science; particularly the

ways in which scientists collaborate and work together to solve problems” (Ryder & Leach, 1999, p. 954). These students then exhibited gains in understandings of the construction of scientific knowledge and that scientific knowledge varies in certainty. In contrast, the findings of one recent study on apprenticeship experiences for secondary learners (Burgin et al., 2011) do not illustrate the same positive relationship between epistemic involvement and gains in NOS ideas from an implicit approach.

Although the authors acknowledge that some of these gains may have been the result of explicit messages through conversations with mentors, specific readings and subsequent reflections on them, they continue to say that for two students in particular, the development of NOS ideas was the result of an implicit approach. “These students attributed this development to their experiences of analyzing data on their own, rather than to any explicit discussions about the practices of professional scientists” (Ryder & Leach, 1999, p. 955). For the other participants, since the students initially prompted the discussions during their participation in science practice, the gains reported in this study are here classified as resulting from an implicit approach.

Teachers. A few empirical studies report on the positive impact resulting from an implicit approach in the context of research apprenticeships for teacher populations (Varelas, House & Wenzel, 2005; Yen & Huang, 1998). Yen and Huang (1998) investigated the impact of an open-ended research experience on preservice teacher NOS ideas. Ten preservice teachers participated in this study as they worked in groups of about three to research the physiology of a tree frog in an authentic context over a period of sixth months. Primary sources of data included open-ended questionnaires and interviews at the beginning and the end of the experience. Preservice teacher

responses at the beginning of the experience reveal that they “associated the nature of scientific knowledge with the process of deriving it and concluded that the research is as objective and unambiguous as scientific results” (Yen & Huang, 1998, p. 10). At the end of the experience the same teachers realized that in reality scientific research “demanded more time and effort than they expected to repeat the experimental trials (replications), and to modify the experimental protocols” (Yen & Huang, 1998, p. 10). The authors describe how unexpected results, experimental failures and blind alleys (Roth, 1994) resulted in some of these changes in NOS ideas. The preservice teacher participants then developed a more sophisticated understanding of the diversity of scientific methods.

Varelas et al. (2005) also investigated the impact of an implicit approach in the context of authentic science experiences on preservice teachers’ NOS ideas. In this study, three preservice teachers participated in a summer research apprenticeship in a professional scientist’s lab the summer prior to their first year of teaching. Each of the three teachers worked on an independent research project of their choosing in the same laboratory environment. The primary sources of data for this study were a series of four interviews conducted with each of the participants. Three of the interviews took place during the experience and one of them took place a year after completion of the apprenticeship. The authors summarize the results of the experience in the following way, “the nonlinearity, messiness, risk taking, evolution over time and complexity of science (their own and others’) came to be defining elements” of the scientist identities formed by these teachers (Varelas et al., 2005, p. 500). In this sense, the teachers exhibited gains in understandings of the diversity of scientific methods. The teachers

also came to understand the interplay between theory and data. Here, the teachers were seen to show gains in understandings of the different forms of scientific knowledge. Finally, the teachers developed an understanding that science is conducted within a community of practice. In the words of one participant, the laboratory, “is a community and I had no idea” (Varelas et al., 2005, p. 506). These teachers then developed sophisticated understandings of the construction of scientific knowledge.

Limited or no gains from an implicit approach in research apprenticeships

Not all studies investigating implicit approaches in the context of research apprenticeships document gains in understandings of NOS ideas. Some studies report limited or no NOS gains resulting from an implicit approach. There are examples of these studies for secondary students (e.g. Bell et al., 2003) and undergraduate students (e.g. Hunter et al., 2007).

Secondary students. In a companion piece to the Barab and Hay (2001) study, middle school student participants of a research apprenticeship are seen to exhibit gains in understandings of the different forms in scientific knowledge but not in the diversity of scientific methods used to construct that knowledge (Hay & Barab, 2001). The setting and the participants of this study are identical to those of the Barab and Hay (2001) study that has already been described. Through the use of an online open-ended test before and after participation in the research apprenticeship, it was demonstrated that these middle school student participants had developed a more sophisticated understanding of the scientific method. That is, they understood to a greater degree the different forms of scientific knowledge including hypotheses. However, interview and field note data revealed that their views of the scientific method restricted their understandings of the diversity of scientific methods. These students experienced an

accelerated apprenticeship experience over a short two-week time period. As such, both the research question and the procedures used to collect data were given to these students. Students were expected to therefore follow the steps of the scientific method in a very systematic way. “Although this emphasis increased the possibility that students experienced applying all of the steps of the scientific method, it may have had the undesirable effect of preventing students from applying their own problem frames and appreciating how one adapts the scientific method to varying conditions” (Hay & Barab, 2001, p. 310). Students therefore did not develop an appreciation the adaptability of the scientific method or the possibilities of other methods used to generate scientific knowledge. Similarly to Ryder and Leach (1999), the authors here are linking NOS gains to epistemic involvement in the research process.

In another study, Bell and colleagues (2003) investigated the impact of an implicit approach on the NOS ideas held by secondary student participants of an apprenticeship program. Using an open-ended questionnaire specifically addressing various NOS aspects (VNOS-B), including all four of Sandoval’s (2005) NOS themes, both prior to and following secondary student participation in an eight-week summer authentic research experience, it was noted that most research participants’ NOS conceptions remained unchanged. “In fact, despite participation in an authentic, inquiry-oriented science apprenticeship program, none of the 10 participants were found to have adequate understandings of [all aspects of] the nature of science” (Bell et al., 2003, p. 494). This is especially interesting considering that the mentors of the ten participants in this study believed that their students had gained more sophisticated NOS understandings as a result of their participation in the program. In the study, it was

observed that one student showed some positive changes related to her understandings of the creativity involved in the construction of scientific knowledge and the diversity of methods used in science. The authors attribute these gains specifically to the epistemic involvement required of the student as she was forced to confront the role that theory played in her research in addition to the amount of reflection that she engaged in with her mentor. Again this link between epistemic involvement and gains in NOS ideas has been observed in other studies (Hay & Barab, 2001; Ryder & Leach, 1999). In this case the learning is not linked to any factors of participation in a research apprenticeship relying on an implicit approach but rather to explicit approaches employed by the student's mentor. However, the specifics of these explicit approaches are not clearly elaborated by the authors. The authors conclude by arguing for making NOS instruction explicit in research apprenticeships through the provision of reflective opportunities for participants.

Buck (2003) also demonstrated a limited impact of an implicit approach in an apprenticeship experience on secondary student conceptions of NOS. In the experience under investigation, 74 high school students and 50 high school science teachers participated in a three-week authentic research experience in either geoscience or biological sciences. Students completed responses to a quantitative instrument called the Beliefs about Science and School Science Questionnaire measuring their NOS conceptions both before and after the experience. This instrument measures student understandings about the certainty of scientific knowledge. "Correct" responses are aligned to current sophisticated understandings that scientific knowledge varies in certainty and is tentative. No statistically significant differences in pre and post scores

were noted for either the students or the teachers (at the $p=0.05$ level). The results indicate that the implicit approach in the experience did not impact participant understandings that scientific knowledge varies in certainty.

In a recent study, a unique perspective on the impact of implicit approaches in research apprenticeships is presented (Van Eijck, Hsu, & Roth, 2009). Drawing from the work of Ryder, Leach & Driver (1999), secondary students' NOS ideas are framed in terms of their "images of science". The purpose of this study was to investigate how student practices in authentic science were translated into their "images of science". Thirteen 11th grade Canadian students participated in the study. The context of the investigation was an internship experience where students apprenticed in a working laboratory on a project related to the quality of drinking water. The laboratory group of which the thirteen students were a part was a very large group consisting of among others a chief scientist, three research scientists, five postdoctoral fellows, thirteen technicians and fifteen graduate students. The high school students volunteered for the apprenticeship and worked in teams of three or four students in the laboratory over a period of two months under the mentorship of one of the technicians. Semi-structured interviews with the participants following the experience were the chief source of data for the study. The interviews were compared with the students' actual practices in the laboratory as evidenced through video recordings of laboratory work and group meetings in addition researcher field notes of observations.

The authors report that some students held sophisticated understandings of the construction of scientific knowledge and that scientific knowledge varies in certainty at the end of the experience whereas other students' perspectives were less informed. It is

stated that these “‘images of science’ were coproduced along a trajectory of translations that was determined by the use of particular actions and tools and a particular division of labor in scientific practice” (Van Eijck et al., 2009, p. 624). Therefore, participation in scientific practice through an implicit approach does impact student NOS ideas but it is highly variable and dependent on many factors. According to this point of view, participation in authentic scientific practice does not guarantee a positive impact on a learner’s images of science. The authors conclude their study with a discussion of the problematic nature of impacting and assessing NOS ideas. They argue that since these images of science are coproduced translations, they are not stable and are not directly related to either implicit or explicit approaches. Issue is taken with studies that are designed to investigate the impact of apprenticeship programs on “accepted” NOS ideas (e.g. Bell et al., 2003).

In a recent study, Aydeniz, Baksa and Skinner (2010) investigated the impact of participation in a research apprenticeship relying on an implicit approach on secondary student understandings of the nature of science and inquiry. The participants in this study were seventeen high school juniors and seniors who were highly gifted in math and science. The learners participated in a number of research projects in the laboratories of a professional scientist on a university campus that were conducted over an extended period of time lasting for at least an entire semester. Most of the students were not involved in the design of a research question, but rather were brought into an on-going research project under investigation in their laboratory placement. Explicit NOS instruction was not a component of this program. The primary source of data for making claims regarding participant NOS ideas was an open-ended survey. The NOS

open-ended survey used in this study had items that specifically addressed all four of Sandoval's (2005) NOS themes. Results indicated that very few students were able to distinguish between data and evidence, most believed in the singularity of the scientific method, most had naïve understandings of how scientists deal with unexpected findings and most did not fully understand the role of theory in science. That being said, most of the students did have sophisticated understandings of the social nature of scientific knowledge generation and that scientific knowledge varies in certainty. In regard to the variability of the certainty of scientific knowledge one student said, "sophistication of new technologies can make new evidence available which could lead to modifications in old theory, and the existing theories can be modified based on new interpretations" (Aydeniz et al., 2010, p. 11). In summary, at the end of this experience, student participants held a mixture of naïve and sophisticated understandings of NOS ideas. The authors summarize their findings in the following way, "These results lead us to believe that engagement in scientific inquiry in authentic contexts alone is not sufficient for novice scientists such as the ones studied in this study to develop adequate understandings of the implicit assumptions of science" (Aydeniz et al., 2010, p. 14). The authors argue for an explicit approach to NOS instruction in the context of apprenticeship experiences.

In a companion piece to the Van Eijck et al. (2009) study, participant discourse about science practice is examined both during and following an authentic internship experience (Hsu, Van Eijck & Roth, 2010). In this study, Hsu and colleagues set out not to investigate student understandings of NOS, but rather student representations of the nature of scientific practice in an authentic context. The participants and laboratory

setting of this study are identical to those of the Van Eijck et al. (2009) study. The data sources included observations, field notes, and video recordings of both the practice of science within the internship setting and the students' final presentations. Additionally, the researchers recorded the initial presentations given by the laboratory technicians to these students. It is these video recordings that served as the primary source of data for this investigation. The authors first analyzed the student presentations and compared them with the presentations given by their mentor technicians at the beginning of the internships. Then they compared these representations of scientific practice with the representations of scientific practice as recorded during actual laboratory work in the internship.

A comparison of the technician and student presentations revealed that the technicians represented science practice as taking place within a community much more regularly than did the students in their presentations (Hsu et al., 2010). The students only rarely emphasized the role of community in scientific practice in their final presentations. Additionally, in their presentations, the technicians emphasized issues of division of labor whereas the students did not. In other words, students did not adequately represent the collaborative nature of scientific practice in their final presentations. This collaborative nature of scientific practice is included within Sandoval's (2005) epistemological theme that scientific knowledge is constructed. Additionally, when examining the experiences of these students within the internship itself, the video data indicated that these high school students had encountered issues of both collaboration and division of labor in conversations held during their experiences. These results seem to be contradictory. The students truly experienced

collaboration and division of labor within their authentic experiences, but the same students failed to reflect on these aspects of scientific practice during their final presentations. The authors use a contextual argument to explain this result. They argue that the process of giving a presentation is quite similar to activities encountered in school situations. Perhaps these students were situating their presentations in the context of school settings rather than the context of authentic science experiences. Students may have been giving their presentations based on expectations they had for what was valued by the audience. They may have felt the need to emphasize their individual contributions to their research project over the actual collaboration that they experienced during the internship. The authors conclude their study with a discussion centered on the notion that student participation in authentic research experiences alone may not be enough to influence the way that students represent science in practice. They offer three suggestions that may help make the invisible qualities of science practice (i.e. collaboration and division of labor) visible in student representations of science. They suggest that students should be presented with opportunities to reflect on their experiences during the experience in addition to after it is completed, that scientists and educators themselves should collaborate to design similar experiences and that students should be provided ownership over the project itself.

Undergraduate students. Similarly, some studies show a limited impact of participation in apprenticeships utilizing an implicit approach on undergraduate conceptions of NOS. In a companion report to the Ryder and Leach (1999) study, it was revealed through interviews that undergraduate student understandings of how

scientists work collaboratively as a community were not consistently sophisticated (Ryder et al., 1999). The participants and setting of this study were identical to the previously described study by Ryder and Leach (1999). The authors systematically compared student interview responses at the beginning and the end of the experience. Whereas the Ryder and Leach (1999) study presents a generally optimistic view of the gains in NOS ideas among these participants, the analysis here paints a slightly different picture. First, it revealed that the students in general held some naïve conceptions of NOS that were unaltered as a result of the apprenticeship experience. For example, the authors recorded that, “all 11 students in our sample made statements indicating that knowledge claims could be proved absolutely. Of these statements, the majority focused on empirical data as the sole grounds for proof” (Ryder et al., 1999, p. 212). This statement speaks to a naïve understanding held by the participants of the variability in the certainty of scientific knowledge. Also, “the influence of social factors, either on the evaluation of knowledge claims or the direction of scientific enquiry, was underrepresented” (Ryder et al., 1999, p. 216). The students therefore held an unaltered and naïve perspective on the construction of scientific knowledge. At the same time however, the authors acknowledge two positive changes in participant understandings of NOS. These are that the students came to understand the importance of “empirical processes” and the “influence of the theoretical ideas of the discipline in guiding the questions which scientists set out to answer” (Ryder et al., 1999, p. 214). These are both positive changes in understandings of the construction of scientific knowledge. The authors conclude that these changes were the result of participation in projects that had an “epistemological focus”. The authors describe that

these projects involved forcing the students to relate data collected to any knowledge claims that were made. The authors also say that these gains were due to an implicit approach. “During interviews, it was clear that those students whose projects had involved working closely with professional scientists and research students had learned a great deal about the world of science, even though such issues were rarely discussed explicitly” (Ryder et al., 1999, p. 214).

The results of another study likewise indicated that there were limited gains in NOS understandings held by undergraduate students resulting from an implicit approach in the context of a research apprenticeship (Hunter et al., 2007). The participants and the context of this study have previously been described in this literature review, so these aspects will not be reexamined here. The study was an interview-based study that involved both the undergraduate participants and their mentors. The results indicated that the students made some limited gains in understanding of the variability of the certainty of scientific knowledge but that these gains were not extensive. This is illustrated in the following quote:

Although most students discussed both learning about how science research is done and their related experience of gains in applying their critical thinking and problem-solving skills to research, fewer students developed a more complex epistemological understanding of the open-ended nature of scientific knowledge and that scientific ‘fact’ may be subject to revision (Hunter et al., 2007, p. 47).

In summary, many empirical studies have demonstrated a limited impact of participation in apprenticeship experiences utilizing implicit approaches on participant conceptions of NOS. These studies are powerful in that many use a more systematic way of measuring participant NOS ideas than do some of the studies that report NOS gains from implicit approaches. For example, some of these studies use validated

questionnaires (e.g. Bell et al., 2003; Buck, 2003; Aydeniz, 2010) and systematic comparisons of multiple interviews (e.g. Hunter et al., 2007) in order to investigate questions specifically related to NOS as a target outcome. In contrast to this, studies of the implicit approach that demonstrate positive changes seem to report gains in NOS understandings that seem to rest more heavily upon student self-reported data and subsequent researcher interpretation.

Explicit Approaches to NOS Teaching and Learning in Research Apprenticeships

Only a handful of studies investigate an explicit approach to NOS teaching and learning in the context of research apprenticeships or other similar non-formal settings (Charney et al., 2007; Liu & Lederman, 2002; Schwartz et al., 2004). In these studies, learners, through instructional components of the experience itself, explicitly encounter target NOS aspects and have explicit opportunities for reflection. Two of these studies document gains associated with an explicit approach to NOS teaching and learning whereas one does not.

Gains from explicit approaches in research apprenticeships

Secondary students. Charney and colleagues (2007) utilized a NOS open-ended questionnaire as a pre and post assessment instrument with 30 high school participants in a four-week summer research apprenticeship. Results of this study indicated that most students' conceptions of NOS shifted towards a more sophisticated understanding of the tentative nature of scientific knowledge or as Sandoval (2005) describes it, an understanding of the variability in the certainty of scientific knowledge. In the study, the authors "focus on the seminars as the primary instrument for the transformation of thinking that we believe took place among the participants" (Charney et al., 2007, p. 198). This transformation of thinking was attributed to the explicit ways in which the

mentor scientist modeled his thought processes during the experience and the reflective nature of questions that were asked of the students by this mentor during seminars. Student participants then wrote responses to these questions in daily journaling activities. It is this focus on the explicit influences of the seminar and the reflective journal as the sources for changes in participant NOS ideas that lead the authors to claim that any gains in understanding were the result of an explicit rather than an implicit approach to the teaching and learning of NOS. "In contrast to some other summer experiences,...the way in which we presented a skeptical eye toward data and some aspects of scientific knowledge constituted an explicit messaging and opportunity for purposeful reflection" (Charney et al., 2007, p. 211).

Teachers. Another study investigated the impact of an explicit and reflective approach to NOS learning on preservice teacher participants of an apprenticeship experience (Schwartz et al., 2004). Participants in this study were enrolled in an internship course that had the following three components: a research setting, reflective journals and seminars. In the research component of the course, research scientists in authentic laboratory environments apprenticed preservice teachers as they worked on a scientific research project. These experiences were classified by the author as being "low inquiry" if they followed predetermined procedures with little to no input, as being "high inquiry" if the preservice teachers made personal decisions that contributed to the design of their research study or as being "moderate inquiry" if the epistemic involvement fell somewhere between these extremes. Of the thirteen participants, eight experienced low inquiry, four experienced moderate inquiry and one experienced high inquiry. Therefore, the majority of the participants did not experience the high levels of

epistemic involvement that Ryder and Leach (1999) link to gains in NOS understandings as a result of apprenticeship experiences utilizing an implicit approach. The journal component of the internship course contained a section for data recording and an additional section for reflection. The reflection was prompted by questions that were given to the participants in order to help them make connections between their research experiences and specific NOS aspects. The following are two examples of reflective questions that students responded to in their journals. “How is what you have seen in your laboratory situation different than the discussions about scientific inquiry and the NOS in the summer course? How is it the same?” “In what ways does what is happening in your laboratory setting relate to ‘science is a complex social activity?’” (Schwartz et al., 2004, p. 639). The seminars in the internship course provided a place for whole group discussions of the research settings, journal prompts and any other relevant issues. The instructor merely used the seminars to facilitate discussions. The seminars were not used to explicitly introduce the preservice teachers to NOS aspects as this had been done in a course that these participants were enrolled in during the previous semester.

The results of the study indicated that eleven of thirteen participants showed “major” gains in NOS understandings based on pre and post responses to an open-ended questionnaire (VNOS-C) and follow up interviews. Additionally, all of the participants “demonstrated abilities to articulate fairly detailed descriptions of all targeted aspects of NOS” (Schwartz et al., 2004, p. 625). These target aspects of NOS included all four of Sandoval’s (2005) NOS themes. All of the participant preservice teachers were able to link their NOS understandings to their specific research

experiences. The authors suggest that the positive changes in NOS understandings were due to participation in seminars and journaling activities designed to explicitly address target NOS outcomes. An interesting finding of this research is that the context of research itself seemed to play less of a role in impacting NOS perspectives than did the seminars and the journaling respectively. The value of the research experience was as a context for reflection rather than as an implicit factor for influencing NOS ideas.

Limited or no gains from an explicit approach in non-formal settings

One study, which warrants discussion here, was conducted in the context of a one-week science camp for gifted Taiwanese middle school students (Liu & Lederman, 2002). Although, this science camp differed in many ways from typical research apprenticeship experiences, it is discussed in this section because the experience was outside of a formal school setting with a focus on “intensive scientific inquiry-based activities, 6 hours per day” (Liu & Lederman, 2002, p. 115). Two major differences between this experience and a research apprenticeship were that the instructors of the camp were not professional scientists, nor was the scientific research conducted in a working professional laboratory. Student participants responded to an open-ended NOS questionnaire at the beginning and at the end of the science camp. This NOS questionnaire was constructed to be sensitive to Chinese culture as it related to the construction of scientific knowledge. For example, one of the questions on this instrument related to the scientific nature of Chinese medicine. During the program, students participated in NOS activities and reflective discussions in addition to their participation in scientific inquiry. Students responded to the questionnaire again at the end of the camp. Many students held sophisticated NOS understandings at the beginning of the program. Most of these views remained unchanged at the end of the

program. The authors attribute these results to a ceiling effect due to these students being highly gifted and already holding sophisticated NOS understandings upon entering the camp. Secondly, they suggest that one week may not be enough time to impact NOS understandings through an explicit approach.

In summary, very few studies have investigated an explicit approach to influencing NOS ideas of participants of apprenticeship programs. Those that have demonstrate the benefits of such an approach (Charney et al., 2007; Schwartz et al., 2004). One study, not technically conducted in the context of a research apprenticeship, does not document positive benefits of an explicit approach in a non-formal camp setting (Liu & Lederman, 2002). Since only three studies took such an approach in the context of non-formal science settings, the next section examines studies that investigated efforts to influence NOS ideas in the context of school science. The interventions in this next section predominately employed an explicit approach to NOS teaching and learning and therefore add much to the discussion of the effectiveness of the explicit approach.

NOS in School Science

Attention is now turned to empirical investigations of the impact of efforts to influence NOS ideas of learners in school science settings. The thirteen studies examined here report on efforts to influence NOS ideas of elementary learners, secondary learners, undergraduate teaching assistants and preservice and inservice teachers who are studying science and/or science education in a formal school setting. Table 2-2 summarizes these studies on the basis of the approach to NOS teaching and learning that was employed, the methods used to assess participant NOS ideas and the results in terms of Sandoval's (2005) four aspects of science epistemology. Only five of

these studies took an implicit approach to NOS teaching and learning. The studies are presented in the table in the order that they are discussed in this section.

Explicit Approaches to NOS Teaching and Learning in School Science

The majority of these studies utilized an explicit approach to NOS teaching and learning. In this approach, the science learners, as a result of purposeful planning on the part of instructors, explicitly encounter NOS aspects. First, studies exhibiting gains from an explicit approach are examined in order of the education level of the participating learners. Next, studies exhibiting little or no gains from an explicit approach are discussed.

Gains from explicit approaches in school science

Elementary learners. Akerson and Volrich (2006) investigated the impact of a preservice teacher's efforts to use an explicit and reflective approach to NOS teaching and learning with her first grade students during her internship. An open-ended questionnaire was used to determine the NOS perspectives of both this preservice teacher (VNOS-B) and her students (VNOS-D). Results indicated that this particular preservice teacher held sophisticated perspectives of NOS whereas her students did not. During the preservice teacher's internship with her students, she explicitly introduced target NOS aspects (the construction of scientific knowledge and that scientific knowledge varies in certainty), embedded them within the science content that was being taught and provided opportunities for her students to reflect on the similarities between classroom activities and the work of practicing scientists through discussion. Following the internship, the students in the class responded to the open-ended questionnaire again. Results indicated that the first grade students had made significant improvements in their understandings of the imagination and creativity involved in the

construction of scientific knowledge and that scientific knowledge varies in certainty. The authors attribute the success of this approach to the prior experiences that the preservice teacher had in her teacher education program both to learn from and to teach using an explicit and reflective approach to NOS instruction.

Akerson and Hanuscin (2007) similarly studied the impact of a three-year long professional development program on inservice elementary science teachers' views of NOS, their classroom practices in implementing NOS strategies and their students' views of NOS. This professional development included traditional explicit and reflective approaches (Lederman & Abd-El-Khalick, 1998) to influencing teacher views of NOS in addition to opportunities for teachers to design and implement similar curriculum with their own students. These activities included the use of pictures with multiple meanings, identifying the internal workings of mysterious devices (black-box activities) and writing stories that account for patterns of animal tracks (Tricky tracks). Open-ended questionnaires (VNOS-B and VNOS-D) at the beginning and the end of this program revealed that both these teacher participants ($n=6$) and their students ($n=33$) held more sophisticated conceptions of NOS at the end of the program. Gains in understanding were observed for all four of Sandoval's (2005) NOS aspects. One result of this intervention was that the preservice teachers were confronted with the lack of explicit NOS instruction present in their existing curriculum and subsequently came to the decision that they would need to make their own curriculum modifications.

Secondary learners. One study investigated the development of seventh grade students' NOS ideas over a three-month period of time (Khishfe, 2008). Eighteen seventh grade students in a class taught by a teacher who held sophisticated

understandings of NOS were the participants of the study. The students participated in two inquiry-oriented units covering the topics of the structure and function of living things and ecosystems and populations. During these units, the students conducted three inquiry-oriented activities. In one of these activities, students were asked to draw and describe an animal given a diagram of its skeleton. In another, students dissected a squid and gave explanations of the functions of structures they encountered. Finally, students collected and identified macro-invertebrates in an effort used to report on the water quality of a river. Four aspects of NOS were explicitly discussed and reflected upon following each of these activities. These aspects were the tentative nature of scientific knowledge, the empirical nature of scientific knowledge, the creative nature of scientific knowledge and the differences between observations and inferences. These aspects correspond with Sandoval's (2005) aspects of the construction of scientific knowledge, the forms of scientific knowledge and that scientific knowledge varies in certainty. Students were administered an open-ended NOS questionnaire three times during the intervention and a subset of the students were interviewed in order to verify author interpretations of student responses to the questionnaire. Findings from this study indicated that the students' views on the targeted aspects of NOS were positively impacted by the explicit and reflective intervention that accompanied the inquiry activities in a school setting. The author suggests that the NOS ideas of these students developed along a continuum of informed perspectives. Along this continuum, students' perspectives were at times "intermediate." "Results showed that the change of students' NOS views, from naïve to more informed, appeared to undergo a developmental process" (Khishfe, 2008, p. 491).

Undergraduates. In another study, a group of science educators concerned with the role that instructor NOS views plays on the development of preservice teacher views sought to examine the effectiveness of a professional development program designed to enhance the NOS ideas of undergraduate teaching assistants of a preservice science teacher education course (Hanuscin et al. 2006). During the program, nine undergraduate teaching assistants met weekly with the faculty instructor of the preservice science teacher education course. In these meetings, the undergraduate teaching assistants were introduced to NOS aspects as presented in science education reform documents (e.g. AAAS, 1993; NRC, 1996), participated in explicit NOS activities previously discussed in this literature review (Lederman & Abd-El-Khalick, 1998), held discussions related to NOS aspects and examined the NOS views of the preservice teachers enrolled in the science teacher education course. Sources of data for this study were pre and post professional development responses to an open-ended questionnaire (VNOS-C), interviews and audio recordings of weekly meetings. Initially, although some undergraduate teaching assistants held sophisticated understandings of some NOS aspects, none of them held sophisticated understandings of all aspects. As a result of this intervention, the participants showed gains in understandings of the construction of scientific knowledge, the diversity of scientific methods, the forms of scientific knowledge and that scientific knowledge varies in certainty.

Teachers. Akerson et al. (2000) also investigated the impact of an explicit and reflective approach on the NOS conceptions of 50 preservice elementary teachers enrolled in a science methods course. At the onset of this course, the preservice teachers completed an open-ended questionnaire. This questionnaire coupled with

semi-structured interviews revealed that the majority of the participants held naïve understandings of NOS. During the course, preservice teachers participated in 10 different hands-on activities (Lederman & Abd-El-Khalick, 1998) that specifically addressed seven targeted NOS aspects including all four of Sandoval's (2005) NOS aspects. These students also completed two reflection papers that asked them to link readings and a video to the seven explicitly addressed NOS aspects. At the end of the course, students again completed the open-ended questionnaire and were interviewed. The results of this post-assessment indicated that substantial NOS gains had been made by many of the participants during the course. Gains were exhibited in all of the target NOS aspects. However, very few of the participants held complete sophisticated views on all seven of the targeted NOS aspects. The findings empirically demonstrated the value of an explicit and reflective approach in impacting preservice science teacher conceptions of NOS.

In another related study, Scharmann, et al. (2005) examined the impact of an explicit and reflective approach in a science methods course on preservice secondary science teachers' views of NOS. The study was conducted with a total of nineteen preservice teachers enrolled in a course entitled "laboratory techniques in the teaching of science" over three semesters that the course was offered. Preservice teachers were explicitly introduced to the NOS aspect that scientific knowledge is constructed, participated in hands-on inquiry activities, read history of science articles and wrote reaction papers to assigned readings as well as a final reflection paper as they specifically examined the on-going debate over issues related to evolution and intelligent design. The instructors of the course used the reflective writings of the

preservice teachers to evaluate the NOS conceptions that they held as well as to revise the course for subsequent semesters that it was offered. The authors concluded that the approach was effective in positively impacting the preservice teachers' views of NOS. They based this claim on the finding that none of the participants in the third offering of the course believed that intelligent design was more scientific than evolution at the end of the course as evidenced in their final reflection papers. The authors suggested that preservice teachers should be provided with multiple opportunities for reflection on NOS constructs, that NOS content should be carefully sequenced and that the issue of science versus religion should be a major topic of discussion. It should be noted that no formal assessment of NOS was conducted either prior to or following participation in this course. Therefore, claims regarding changes in preservice teacher NOS perspectives should appropriately be questioned.

Lotter et al. (2009) similarly looked at the impact of repeated cycles of reflection and instruction on preservice secondary science teachers' views of NOS and on their enactment of scientific inquiry in the classroom. The investigators utilized a questionnaire called the Views of Scientific Inquiry and written reflection papers to examine the preservice teachers' NOS perspectives and teaching philosophies. Lesson plans that they wrote and implemented during their practicum experiences were examined for their inquiry content and explicit attention to NOS. The nine participants in this study were all observed to grow in their understandings of NOS (the construction of scientific knowledge, and the diversity of scientific methods) and in their implementation of inquiry experiences over their practicum experience. The explicit attention that these preservice teachers gave to NOS was less evident in their planning for instruction, and

when it was present in lesson plans it was usually as a supplemental addition even though it was a required component of the practicum course. The authors of this study attributed the success of the approach to the repeated opportunities for preservice teachers to practice teaching and subsequently write reflections of their experiences.

Limited or no gains from explicit approaches in school science

Only one study demonstrates limited gains in NOS ideas among learners experiencing an explicit approach (Abd-El-Khalick & Lederman, 2000). It should be noted that the undergraduate students in this study did not participate in reflective opportunities.

Undergraduate students. Abd-El-Khalick and Lederman (2000) utilized a pre and post open-ended questionnaire to examine the impact of an explicit approach used in the context of history of science courses on 166 undergraduate and graduate students' and on 15 preservice science teachers' views of NOS. They noticed very little changes in participant NOS perspectives across all targeted aspects of NOS ideas. However, they did document greater positive changes among the preservice science teachers who had prior experiences with the target NOS aspects in science methods courses. This study suggests that preservice teachers should be exposed to NOS in their methods course prior to enrollment in history of science courses as participation in history of science courses alone may not be an explicit enough approach to influencing learner NOS ideas.

The results of this entire empirical literature base demonstrate that the explicit approach, when accompanied with reflective opportunities, is very effective at influencing learner conceptions of NOS in traditional school settings for a wide variety of learners from elementary students to inservice science teachers.

Implicit Approaches to NOS Teaching and Learning in School Science

Only a handful of studies claim to investigate the impact of an implicit approach to NOS teaching and learning in the context of school science settings. Those that actually do investigate an implicit approach look specifically at the influence of participation in inquiry activities in school settings on the development of learner NOS ideas.

Gains from implicit approaches in school science

Secondary learners. One study seems to indicate the positive impact of an implicit approach in a school science setting (Yerrick, 2000). In this investigation, marginalized high school students participated in a course that emphasized open inquiry experiences. The experiences were classified by the author as being “open” because the students posed questions and designed methods for collecting empirical data that they analyzed in order to obtain answers. An example of one of the student-posed questions was, “What makes a light bulb burn out when the glass breaks?” (Yerrick, 2000, p. 815). Five of the students were interviewed at the beginning of the course and then again after twenty weeks of participating in the open inquiry investigations. The interview protocols focused on the nature of the construction of arguments within scientific discourse practices. At the beginning of the experience, students held the perspective that knowledge claims in scientific arguments were absolute and correct. During the second interview, students’ understandings of knowledge claims shifted to reflect their tentative nature. Student language when talking about the warrants of these claims included words like “might”, “probably” and “I think” (Yerrick, 2000, p. 822). The findings of this study indicated that lower track students participating in highly authentic open inquiry experiences may develop sophisticated understandings of NOS as a result of an implicit approach in a school science setting.

Teachers. Palmquist & Finley (1997) examined the influence of a science teacher program on preservice teacher NOS ideas. Using a survey at the beginning and the end of the program accompanied by follow-up interviews, they demonstrated significant gains in participant NOS ideas. Of the nine preservice teachers in this study, only two of them held overall sophisticated views of NOS at the beginning of the program. At the end of the program, the number increased to seven. The authors attributed the gains to an implicit approach utilizing conceptual change approaches and cooperative learning strategies. The gains were exhibited in the NOS areas of the construction of scientific knowledge, the diversity of scientific methods and the forms of scientific knowledge.

Others have questioned the degree to which the approach used in this study can be classified as implicit (Bell, Lederman & Abd-El-Khalick, 1998). Critics say that, “a closer look at Palmquist and Finley’s data indicate that substantial direct instruction was provided, and supports the view that the nature of science, like any other cognitive outcome, should be addressed explicitly” (Bell et al., 1998, p. 1057). Indeed, the data from the Palmquist and Finley (1997) study seem to advocate for the merits of an explicit approach rather than an implicit approach.

Limited or no gains from implicit approaches in school science

Elementary learners. Wu & Wu (2010) explored how fifth grade students’ practical epistemologies (Sandoval, 2005) developed over the course of an inquiry intervention. The intervention consisted of students participating in ten different inquiry activities related to force and motion. The inquiry activities were described by the authors as being examples of guided-inquiry in that the students were provided with the questions to be investigated. Data were collected in the form of video recordings, field notes, interviews and pre and post-tests of the participants’ explanation skills. The

interviews were designed in order to elicit students' practical epistemologies of science. For example, students were asked in the interviews, "Does your conclusion count as scientific knowledge? Why or why not? What is scientific knowledge?" (Wu & Wu, 2010, p. 8). Results of the study indicated that the students' inquiry skills increased during the intervention as a result of comparisons of the pre and post-tests of students' explanation skills. Pre-interviews revealed that most of the students held naïve understandings of NOS. Although a few students showed some gains in understandings of NOS over the course of the experience, the authors concluded that most students' understandings of the variability in the certainty of scientific knowledge remained unchanged. Additionally, the authors stated that some students' conceptions of the diversity of methods in science were sophisticated at the beginning of the intervention. "Yet, in post-interviews, some students changed their ideas, held a more naïve view toward their own inquiry, and believed that there was only one method to conduct their experiments" (Wu & Wu, 2010, p. 14). Even though the views of their own practical epistemologies were negatively influenced, their views of professional scientists and the diversity of scientific methods remained unchanged. The authors discussed how students who held sophisticated understandings of NOS showed the greatest development of inquiry abilities. They concluded with a rationale for a more explicit and reflective approach to influencing practical epistemologies than the one that was taken here.

The results of this study seem to correspond with those by Ryder and Leach (1999) in their investigation of the links between gains in NOS ideas among participants of a research apprenticeship utilizing an implicit approach and the epistemic involvement that they experienced. Here in a school science setting relying on an

implicit approach, no impact on NOS ideas through participation in inquiry experiences is evidenced when the students take no active role in the development of a research question or the methods used to investigate it.

Secondary learners. Other studies demonstrate the limits of the implicit approach on secondary student NOS ideas in the context of school science settings. Moss (2001) conducted an interview-based study with five high school students of varying academic ability levels. The students participated in a project-based environmental science class that involved participation in high-level inquiry experiences in field settings albeit not at professional settings with mentor scientists. Results of this study indicated that all of the students held sophisticated understandings that scientific knowledge varies in certainty. However, the majority of the participants showed limited change over an entire school year in their NOS ideas representing all of Sandoval's (2005) themes. That being said, a few of the participants did show positive changes in NOS understandings that the author attributed to participation in science inquiry. For example, when one student's ideas about how "science explains phenomena" exhibited positive change, the author said, "we attribute this development to his participation in real science data collection activities in which he was able to explore the notion of causality regarding forest health and air pollution" (Moss, 2001, p. 787). The argument is made that while an explicit approach would have been more effective than this implicit approach exhibited, the impact of participation in inquiry activities cannot be ignored. "Although we believe nature of science learning should be made explicit throughout science instruction, there may be an important role for implicit messages as well, as student conceptions did evolve in certain cases as described in this report" (Moss, 2001, p. 788). Again it must

be emphasized that the author believed that the implicit approach had a very limited impact on these participant's NOS ideas.

Another study investigated the influence of an implicit approach for secondary learners in the context of a traditional school setting (Sandoval & Morrison, 2003). In this study, high school students participated in a four-week inquiry based unit on evolution. The researchers investigated how such participation in inquiry might influence students' understandings of nature of science through an implicit approach. During the four-week unit, students participated in two computer based guided-inquiry experiences where students were provided with the questions to investigate. In the first, students investigated natural selection as it related to finches on the Galapagos Islands. In the second, students explored how bacteria could develop antibiotic resistance. Eight students were interviewed before and after the unit in order to examine their NOS ideas. The authors found that the students thought that scientific investigations were about establishing right ways of viewing the world. The students seemed to lack a sophisticated understanding of how science varies in certainty. Additionally, the students held naïve understandings of the social construction of scientific knowledge. The results indicated that such understandings on the part of the students did not change as a result of the implicit approach. In their discussion, the authors suggested that the students did not hold stable coherent NOS understandings. They also mentioned that the results they obtained may have been influenced by the interview protocols themselves and might have reflected a discrepancy between students' professional epistemologies and their views of their own engagement in scientific practices. "Students may not see their experiences as real science...The important

epistemic discourse, then, is to relate students' inquiry experiences directly to the practice of professional science" (Sandoval & Morrison, 2003, p. 383). The authors argue for making explicit connections to students' practical work on NOS assessments in addition to providing opportunities for explicit discourse regarding science epistemologies while students are conducting scientific inquiries. These suggestions are different from those made by science educators arguing for the use of an explicit approach.

In summary, explicit and reflective approaches are seen to be effective in influencing learner NOS ideas, whereas implicit approaches through inquiry experiences are not as effective in the context of school science settings. Perhaps this is due to the great differences between professional science experiences and school science experiences in terms of the features of canonical authenticity.

Studies Comparing Various Approaches in School Science Settings

Finally, empirical studies that compare the effects of various approaches to the teaching and learning of NOS are discussed. No studies of this type have been conducted in the context of a research apprenticeship. As such, all of the studies reviewed here report findings speaking to the effectiveness of various approaches in traditional school science settings. Six comparison-of-approaches studies are reviewed in this section. Table 2-3 summarizes these studies according to the participants, the approaches that were compared, the methods used to do so and the reported results. These studies are presented in the table in the order that they are discussed. Again discussion of target NOS aspects has been couched in terms of Sandoval's (2005) four aspects of science epistemologies. It should be emphasized that Sandoval's aspects

are used even when the authors of these studies describe their results in other specific terms from different consensus lists of NOS aspects.

Secondary learners. The earliest study reviewed here examined the effectiveness of an inquiry-based approach to influencing participant NOS understandings compared with a traditional lecture-oriented approach in a middle school science classroom (Meichtry, 1992). Over the course of 26 weeks, two groups of students were compared. These students included sixth, seventh and eighth grade students from the same school district. One of the two groups (n=809) participated in an innovative curriculum that placed an “emphasis on questions that are appealing to adolescents, activities that improve reasoning, decision making, and habits of disciplined inquiry, and the use of cooperative learning as the primary grouping strategy” (Meichtry, 1992, p. 390). This first group of students served as the experimental group. The other group of students (n=491) was taught science in a traditional manner. Student understandings of the construction of scientific knowledge, the forms of scientific knowledge and that scientific knowledge varies in certainty were assessed at the beginning and the end of the school year by using a modified version of the Nature of Scientific Knowledge Scale (Rubba & Anderson, 1978), a Likert-scale instrument. Results revealed no significant differences in changes in NOS understandings between the two groups. In fact, student understandings of the construction of scientific knowledge actually decreased significantly for the experimental group and did not for the control group. The authors make the argument that even though the curriculum utilized by the experimental group was designed to explicitly introduce NOS ideas, the ideas were “not always being directly conveyed to students

through either the written curriculum...or by the teachers” (Meichtry, 1992, p. 402). For this reason, the approach is classified here as a predominately implicit one utilizing inquiry experiences. It is not altogether surprising then that no impact on student NOS ideas from an implicit approach in the context of a school setting was observed in this study. The results are consistent with those of Moss (2001) and Wu and Wu (2010) in demonstrating the limited impact of the implicit approach utilizing inquiry in school science settings. It is worth mentioning that science educators currently have questions regarding the validity of forced-choice quantitative instruments such as the Nature of Scientific Knowledge Scale for assessing NOS ideas held by learners (Lederman et al., 1998).

Wagner & Levin (2007) similarly compared an implicit approach to NOS teaching and learning with a traditional approach to science teaching and learning. In their study, 97 middle school science students from Israel were divided into two groups. One of the groups (the experimental group) studied five different science topics and participated in informal and reflective writing tasks after each. The informal writing tasks were in the forms of stories, diaries and debates. The following is an example of one of the informal writing tasks that followed a unit on heat and temperature. “An additional sun has appeared in the sky of our planet. The sun radiates continuous heat on earth. Write a diary of your own or the diary of someone else describing the effect on our world” (Wagner & Levin, 2007, p. 311). The reflective writing tasks prompted students to think about the challenges of the informal writing tasks. Students in the other group (the control group) studied the same science topics in a traditional way with no writing or reflective opportunities. In order to assess participant NOS ideas both before and after

the intervention, the authors utilized a Likert-scale instrument that measured participant understandings of the construction of scientific knowledge and that scientific knowledge varies in certainty. Results indicated a significant impact on understandings of these dimensions of NOS for participants in the experimental group. On the other hand, participants in the control group exhibited no gains in their NOS ideas.

To a certain degree, these results are consistent with the findings of Meichtry (1992) in that studying science content from a traditional approach does not influence participant understandings of NOS. However, the results are unique in the sense that they illustrate positive changes in participant NOS understandings resulting from an implicit intervention that did not rely on an inquiry approach. This study demonstrates the power of reflective writing apart from participation in hands-on scientific inquiry on participants' understandings of NOS.

Another study specifically compares an implicit inquiry approach like that of Meichtry (1992) with an explicit and reflective approach to NOS teaching and learning in the context of middle school science in a classroom setting (Khishfe & Abd-El-Khalick, 2002). In this study, 62 sixth graders from Lebanon were divided into two groups. Both groups participated in the same six inquiry activities over 10 weeks and were given an open-ended NOS questionnaire targeting the multiple NOS aspects including the construction of scientific knowledge and that scientific knowledge varies in certainty prior to and following the intervention. One of these groups received no NOS instruction and therefore any gains in NOS understandings would have resulted from participation in scientific inquiry alone, an implicit approach. The other group was explicitly

introduced to the targeted NOS aspects and discussed the ways that they related to the inquiry activities in which they participated.

The students that received explicit instruction in NOS exhibited more gains in understandings of the targeted aspects than did the implicit group. Such findings suggest that an explicit and reflective approach to NOS instruction is more powerful than an implicit approach. However, given the nature of the inquiry activities that these students participated in, there are questions regarding the transferability of these findings to more authentic contexts such as research apprenticeships. Of the six inquiry activities that the students participated in, four were simple experiments and none involved ill-defined problems that could be perceived to be of any personal relevance to the students. In fact, all of the inquiry activities were guided by questions that were provided to the students without any explicit connections to their everyday lives. For example, one of the activities involved the investigation of the research question “does the amount of available air affect the burning of a candle?” Students were given different sized jars and same-sized candles. They then measured either the time it took for the candle to burn out or compared the relative brightness of the burning candles. Based on Chinn and Malhotra’s (2002) framework for assessing the authenticity of inquiry activities, experiences like these are far removed from the actual practice of working scientists. Additionally, the experiences were disconnected from the real-world concerns of these students. In real science practice, scientists are personally invested in meaningful research. This could explain why students who participated in the activities without explicit instruction on target NOS aspects exhibited no development of

a deeper understanding of NOS as assessed by questionnaires that asked them about the practices of working scientists.

A recent study, similar to that of Khishfe and Abd-El-Khalick (2002), was conducted in order to investigate the impact of explicit and reflective discussions of NOS following laboratory experiences for middle school students on their conceptions of the construction of scientific knowledge and that scientific knowledge varies in certainty (Yacoubian & BouJaoude, 2010). Yacoubian and BouJaoude also sought to examine if middle school students exhibited any gains in understandings of NOS through participating in the inquiry experiences without any opportunities for explicit reflection. The participants of this study were 38 sixth grade students from Lebanon enrolled in the same science course in two different sections. Randomly, one of the sections was assigned to be the control group and one was assigned to be the experimental group.

Both the control group and the experimental group completed the same eight guided-inquiry laboratory investigations working in groups of two. The researchers classified these investigations as “guided” in that the students were provided with both the research question and the methods used to investigate it, but the solution was unknown to them. “Examine a dramatic chemical change”, “explore the characteristics of acids and bases”, and “investigate the digestion of starch” were the listed objectives for three of these experiences (Yacoubian & BouJaoude, 2010, p.1235). Following participation in each laboratory inquiry, the students in the control group answered individual questions regarding the results of their experiments. “What evidence do you have that a chemical change took place?” is an example of one of the questions from the dramatic chemical change inquiry (Yacoubian & BouJaoude, 2010, p.1252). The

teacher then engaged the class in an extended discussion about the science content relevant to the inquiry they had just completed. Alternatively, the students in the experimental group answered individual open-ended NOS questions following each laboratory investigation. “Did you and your friends explain the observations in step 7 in the same way? Why? Do scientists explain observations in the same way?” are examples of open-ended NOS questions from the dramatic chemical change inquiry (Yacoubian & BouJaoude, 2010, p.1251). Following this, the students in the experimental group participated in an extended whole-class discussion in which the teacher asked the students additional reflective questions intended to make target NOS aspects explicit.

A modified form of the VNOS (Abd-El-Khalick, 2002) was used as a pre and post assessment for both the control and the experimental group. This questionnaire allowed for students to communicate their own NOS perspectives through open-ended responses. In addition to the questionnaire responses, other data sources for this investigation included written responses to the open-ended NOS post-lab questions from the experimental group, videotapes of all the inquiry experiences from both groups, and follow-up interviews from participants of both groups. Analysis of the questionnaire responses revealed that at the beginning of the experience, most of the students in both groups held inadequate views of all of the target NOS aspects with the most inadequate views being held in regard to the construction of scientific knowledge. At the end of the experience, most of the students in the control group continued to hold the same inadequate NOS views, whereas a substantial number of students in the experimental group shifted their perspectives on target NOS aspects to more adequate views. The

authors concluded that an implicit approach to NOS through inquiry activities did not influence student perceptions of NOS. They mentioned their study as lending further support to the notion that the most effective way to influence NOS conceptions is through explicit and reflective approaches. These findings are consistent with those of Khishfe and Abd-El-Khalick (2002).

The authors do address some of the anomalies in their data set. One of these is that some of the students (although a small percentage) in the control group did exhibit positive changes in NOS understandings. The authors attribute this to the epistemic involvement required of the students as they participated in inquiry experiences. They make the same argument made by Bell and colleagues (2003) to account for positive changes in NOS perspectives they observed in one student participating in an authentic research experience. Another anomaly is that a number of the students in the experimental group did not exhibit positive changes in their perspectives regarding the target aspects of NOS. This is explained using videotape data that indicate that not all of the students were participating in the reflective discussions following the inquiry activities. Additionally, the authors say that perhaps some students held misconceptions regarding NOS that were so deeply entrenched that the amount of time and specific attention given to these misconceptions through the experimental treatment was not enough to influence conceptual change.

Again, as with the Khishfe and Abd-El-Khalick (2002) study, the results of this study are not entirely surprising. Students in the implicit group participated in very tightly controlled guided-inquiries in which they investigated questions that really had no personal value to them through provided laboratory procedures that did not come close

to representing the actual practices of working scientists. It follows that merely participating in these activities had no impact on the students' understandings of NOS as indicated by assessments that asked them about the practices of professional scientists.

Having demonstrated the comparative effectiveness of the explicit and reflective approach over the implicit inquiry embedded approach (Khishfe & Abd-El-Khalick, 2002), Khishfe & Lederman (2006) turned their attention to a comparison of the effectiveness of different types of explicit/reflective approaches in influencing learner NOS ideas. In this study, 42 ninth grade students were divided into two groups. One group experienced an explicit approach in the context of a unit on global climate change. The authors describe this approach as an explicit integrated approach. The other group studied NOS aspects as a stand-alone unit apart from the global climate change context. This group is described as experiencing an explicit non-integrated approach. All participants responded to an open-ended NOS questionnaire at the beginning of the six-week intervention and again at the end of the experience. Follow-up interviews of participants were used to further clarify their responses to the questionnaire. Results indicated that prior to instruction, students from both groups held naïve understandings of all four of Sandoval's (2005) NOS themes. Following the intervention, participants from both groups exhibited gains in understandings of all target NOS aspects. The authors document "slightly" more gains in the integrated group. The findings speak to the relative effectiveness of the explicit approach as has been documented previously (e.g. Khishfe, 2008). The findings also suggest that there

may be some benefit (albeit small) to teaching NOS aspects in the context of some broader scientific topic.

Teachers. Bell et al. (2010) take the work of Khishfe and Lederman (2006) a step further by comparing four treatments: An implicit integrated, an implicit non-integrated, an explicit integrated and an explicit non-integrated approach to NOS teaching and learning in the context of a preservice science teacher education program. The explicit groups participated in NOS activities previously described (Lederman & Abd-El-Khalick, 1998) followed by explicit and reflective NOS discussions. The implicit groups participated in the same NOS inquiry activities without any explicit and reflective debriefing. The integrated groups conducted the activities in the context of a global climate change unit whereas the noni-ntegrated groups participated in the activities as part of a stand-alone unit. Using an open-ended questionnaire (VNOS-B) and follow-up interviews with 75 preservice teachers, the authors demonstrated significant gains in understandings of all of Sandoval's (2005) NOS themes for both explicit groups. They also demonstrated that preservice teachers who experienced the explicit non-integrated approach were able to make connections between their NOS understandings and new situations. These findings are consistent with the results of Khishfe and Lederman (2006). They also add to the results of this previous study in that they illustrate the ineffectiveness of an implicit inquiry approach to NOS teaching and learning regardless of whether or not it is integrated within a certain science topic.

Comparison studies of various approaches to the teaching and learning of NOS in the context of school science settings reveal the overall merits of explicit approaches over implicit approaches. There is one exception to these general results that

demonstrates the effectiveness of the uses of reflective writings apart from explicit NOS instruction in positively influencing participant NOS ideas (Wagner & Levin, 2007). The limited effectiveness of an implicit approach in the context of inquiry experiences in classroom experiences (e.g. Meichtry, 1992; Khishfe & Abd-El-Khalick, 2002; Yacoubian & BouJaoude, 2010) stands in contrast to the relative effectiveness of this approach in highly authentic research apprenticeship experiences (e.g. Barab & Hay, 2001; Burgin et al., 2011; Richmond & Kurth, 1999; Ryder & Leach, 1999). Perhaps this is due to the limited levels of authenticity present in classroom science inquiry activities in terms of the differences between participation in them and in professional scientific practices.

Summary

Research apprenticeships are contexts for science learning that provide opportunities for participation in scientific practices that are vastly more canonically authentic than those found in the typical school science setting (Chinn & Malhotra, 2002). Participation in research apprenticeships has been empirically demonstrated to result in the formation of science identities (e.g. Bliecher, 1996; Charney et al., 2007; Seymour et al., 2004) and the development of scientific skills and understandings (e.g. Burgin et al., 2011; Ritchie & Rigano, 1997; Ryder & Leach, 1999). Among the understandings developed through participation in research apprenticeships are NOS ideas (Sadler et al., 2010).

NOS ideas have been conceptualized in many different ways, but recently have been described in terms of four aspects; the construction of scientific knowledge, the diversity of scientific methods, the forms of scientific knowledge and that scientific knowledge varies in certainty (Sandoval, 2005). Other lists of consensus NOS aspects

(e.g. Lederman et al., 2002) can be condensed into these four themes. Assessing learner conceptions of NOS is problematic, but most science educators agree on replacing traditional quantitative instruments with open-ended questionnaires, interviews and ethnographic approaches (Lederman et al., 1998).

Studies investigating the impact of various approaches to NOS teaching and learning in the context of research apprenticeships almost overwhelmingly look at the merits of the implicit approach (e.g. Aydeniz et al., 2010; Bell et al., 2003; Bleicher, 1996; Burgin et al., 2011; Ritchie & Rigano, 1996). Of the eighteen studies reviewed here that investigate the impact of “doing” professional science on participant understandings of NOS ideas, eleven report gains from such an implicit approach (e.g. Bleicher, 1996; Ritchie & Rigano, 1996) and seven report limited or no gains (e.g. Aydeniz et al., 2010; Bell et al., 2003). Such results are inconclusive regarding the effectiveness of the implicit approach in the context of research apprenticeship experiences. Only three studies investigate the impact of an explicit approach to NOS teaching and learning in the context of research apprenticeships and other non-formal settings (Charney et al., 2007; Liu & Lederman, 2002; Schwartz et al., 2004). Two of these studies demonstrate positive gains in NOS understandings associated with an explicit approach.

Since, only three studies reviewed here investigate the explicit approach in the context of research apprenticeships, studies examining approaches to the teaching and learning of NOS in the context of school science were discussed. Of the thirteen studies falling under this category, eight took an explicit approach (e.g. Akerson & Hanuscin, 2007; Khishfe, 2008; Lotter et al., 2009). All but one of the interventions described in

these studies (Abd-El-Khalick & Lederman, 2000) also provided participants with reflective opportunities. These explicit and reflective approaches to NOS teaching and learning in school contexts consistently demonstrated positive impacts on participants' NOS conceptions. Of the five studies conducted in school settings that investigated the impacts of participation in science inquiry on the development of NOS ideas, three demonstrated no significant gains from implicit approaches (Moss, 2001; Sandoval & Morrison, 2003; Wu & Wu, 2010).

Finally, the only studies that systematically compared various approaches to NOS teaching and learning were conducted in school science settings (e.g. Meichtry, 1992; Khishfe & Abd-El-Khalick, 2002; Yacoubian & BouJaoude, 2010). When explicit approaches were compared with implicit inquiry approaches, the explicit approach was consistently demonstrated to be more effective. However, due to the limited authentic nature of inquiry experiences in school settings, questions remain as to the transferability of these results to more authentic settings such as research apprenticeships. It was also demonstrated through these studies that at least some relationship exists between reflective writing opportunities and implicit impacts on participant NOS ideas (Wagner & Levin, 2007).

In conclusion, the benefits of the explicit and reflective approach to NOS teaching and learning are consistently revealed in the empirical literature reporting on this approach in both school and research apprenticeship experiences. However, the impacts of the implicit approach are debatable in the context of authentic science experiences. Additionally, there is very limited understanding of the role that reflection plays in influencing NOS ideas. Finally, questions remain in regard to the individual

aspects of research apprenticeship experiences outside of accompanying organized seminars that may possibly be related to the development of sophisticated NOS understandings (Burgin et al., 2011). Is epistemic involvement an important experiential component of research apprenticeships in implicitly influencing NOS ideas? Some would argue yes (Ryder and Leach, 1999) whereas others are not so convinced (Burgin et al., 2011). This present study is an attempt to further investigate some of these unanswered questions and create deeper understanding of the merits of various approaches to NOS teaching and learning in the context of research apprenticeships.

Table 2-1. Studies reporting on impacts on NOS ideas in the context of research apprenticeships

Refs.	P(n) ^a	Approach	Methods	Results ^b
Cooley & Bassett (1961)	SL (55)	Implicit	Pre-post design: FAS,	Author Reported Gains (V)
Bleicher (1996)	SL (1)	Implicit, Reflection	Field notes, videos	Gains (C & V)
Ritchie & Rigano (1996)	SL (2)	Implicit	Field notes, interviews	Gains (C & V)
Richmond & Kurth (1999)	SL (7)	Implicit, Reflection	Interviews, journals	Gains (C & V)
Barab & Hay (2001)	SL (24)	Implicit, Reflection	Field notes, videos, interviews and elect. notebooks	Gains (C)
Burgin et al. (2011)	SL (18)	Implicit	Multiple interviews	Some gains (C & V)
Sabatini (1997)	UG (10)	Implicit	Focus group interview, Questionnaire	Gains (C, D & F)
Ryder & Leach (1999)	UG (11)	Implicit	Interviews	Gains (C & V)
Yen & Huang (1998)	PT (10)	Implicit	Pre-post design: questionnaires interviews	Gains (D)
Varelas et al. (2005)	PT (3)	Implicit	Multiple interviews throughout the program	Gains (C, D & F)
Hay & Barab (2001)	SL (24)	Implicit, Reflection	Pre-post design: open-ended web based tests, field notes, videos, interviews	Gains (F), No Gains (D)
Bell et al. (2003)	SL (10)	Implicit	Pre-post design: VNOS-B and interviews	No significant gains (C, D, F & V)
Buck (2003)	SL (74)	Implicit	Pre-post design: interviews, surveys, BASSQ	No significant gains (V)
Van Eijck et al. (2009)	SL (13)	Implicit	Interviews, field notes and videos	Varying levels of understanding (C & V)
Aydeniz et al. (2010)	SL (17)	Implicit	Likert-scale surveys and VOSI	No significant gains (D & F), Sophisticated ideas (C & V)

Table 2-1. Continued

Hsu et al. (2010)	SL (13)	Implicit	Field notes and videos	No gains (C)
Ryder et al. (1999)	UG (11)	Implicit	Pre-post design: interviews	No gains (V), Some gains (C)
Hunter et al. (2007)	UG (76) & FA (55)	Implicit	Interviews	Limited gains (V)
Charney et al. (2007)	SL (30)	Explicit, Reflection	Pre-post design: checklist, questionnaire, AP bio test questions, journals	Gains (V & F)
Schwartz et al. (2004)	PT (13)	Explicit, Reflection	Pre-post design: VNOS-C, interviews	Gains (C, D, F & V)
Liu & Lederman (2002)	SL (29)	Explicit	Pre-post design: questionnaire, interviews	No significant gains (C, D, F & V)

BASSQ, Beliefs about Science and School Science Questionnaire; FAS, Facts about Science test; VNOS-B, Views of the Nature of Science Questionnaire; VOSI, Views of Science Inquiry Questionnaire

^aParticipants (P): Secondary Learners (SL), Undergraduate Students (UG), Preservice Teachers (PT) or Faculty Advisors (FA).

^bResults according to Sandoval's (2005) NOS themes: construction of scientific knowledge (C), the diversity of scientific methods (D), the different forms of scientific knowledge (including hypotheses, models, theories and laws) (F), scientific knowledge varies in certainty (V).

Table 2-2. Studies reporting on impacts on NOS ideas in the context of school settings

Refs.	P(n) ^a	Approach	Methods	Results ^b
Akerson & Volrich (2006)	EL/PT (14/1)	Explicit, Reflection	Pre-post design: VNOS-B, VNOS-D, interviews, field notes	Gains for EL (C & V)
Akerson & Hanuscin (2007)	EL/IT (33/6)	Explicit, Reflection	Pre-post design: VNOS-B, VNOS-D, interviews, field notes, lessons	Gains for IT and EL (C, D, F & V)
Khishfe (2008)	SL (18)	Explicit, Reflection	Pre-post design: Questionnaire and interviews	Gains (C, F & V)
Hanuscin et al. (2006)	UTA (9)	Explicit, Reflection	Pre-post design: VNOS-C, interviews and meeting recordings	Gains (C, D, F & V)
Akerson et al. (2000)	PT (50)	Explicit, Reflection	Pre-post design: Open-ended questionnaires, interviews	Gains (C, D, F & V)
Scharmann et al. (2005)	PT (19)	Explicit, Reflection	Analysis of reflection writings and class discussion	Gains (C)
Lotter et al. (2009)	PT (9)	Explicit, Reflection	Pre-post design: VOSI, interviews, reflection papers, portfolios	Gains (C & D)
Abd-El-Khalick & Lederman (2000)	UG/PT (166/15)	Explicit	Pre-post design: Questionnaires, interviews	Limited gains (C, D, F & V)
Yerrick (2000)	SL (5)	Implicit	Pre-post design: interviews, videos	Gains (V)
Palmquist & Finley (1997)	PT (15)	Implicit	Pre-post design: surveys, interviews	Gains (C, D & F)
Wu & Wu (2010)	EL (68)	Implicit	Videos, field notes, interviews	No significant gains (D & V)
Moss (2001)	SL (5)	Implicit	Interviews	No significant gains (C, D, F & V)
Sandoval & Morrison (2003)	SL (8)	Implicit	Pre-post design: interviews	No significant gains (C & V)

PD, professional development; VNOS, Views of the Nature of Science Questionnaire

^aParticipants (P): Elementary Learners (EL), Secondary Learners (SL), Undergraduate Students (UG), Undergraduate Teaching Assistants (UTA), Preservice Teachers (PT) or Inservice Teachers (IT).

^bResults according to Sandoval's (2005) NOS themes: construction of scientific knowledge (C), the diversity of scientific methods (D), the different forms of scientific knowledge (including hypotheses, models, theories and laws) (F), scientific knowledge varies in certainty (V).

Table 2-3. Studies comparing various approaches to impacting NOS ideas in school settings

Refs.	P(n) ^a	Approaches	Methods	Results
Meichtry (1992)	SL (1300)	Implicit (Inquiry) versus traditional (no inquiry)	Pre-post design: MNSKS	No significant differences in changes in NOS ideas for both groups.
Wagner & Levin (2007)	SL (97)	Implicit (Reflection) versus traditional	Pre-post design: Likert-scale assessment	Gains with the reflection group. No gains with the traditional group.
Khishfe & Abd-El-Khalick (2002)	SL (62)	Implicit versus explicit/reflective	Pre-post design: Questionnaire, interviews	Gains with the explicit/reflective group. Minimal gains with the implicit group.
Yacoubian & BouJaoude (2010)	SL (38)	Implicit versus explicit/reflective	Pre-post design: POSE, videotapes, interviews	Gains with the explicit/reflective group. Minimal gains with the implicit group.
Khishfe & Lederman (2006)	SL (42)	Explicit integrated (global warming context) versus explicit nonintegrated	Pre-post design: Questionnaire, interviews	Gains in both groups. "slightly" more in integrated group.
Bell et al. (2010)	PT (75)	Comparison of Implicit integrated, implicit nonintegrated, explicit integrated and explicit nonintegrated	Pre-post design: VNOS-B, interviews, artifacts	Gains with both explicit groups. Minimal gains with both implicit groups.

MNSKS, Modified Nature of Scientific Knowledge Scale; VNOS-B, Views of the Nature of Science Questionnaire; POSE, Perspectives on Scientific Epistemology Questionnaire

^aParticipants (P): Secondary Learners (SL) or Preservice Teachers (PT)

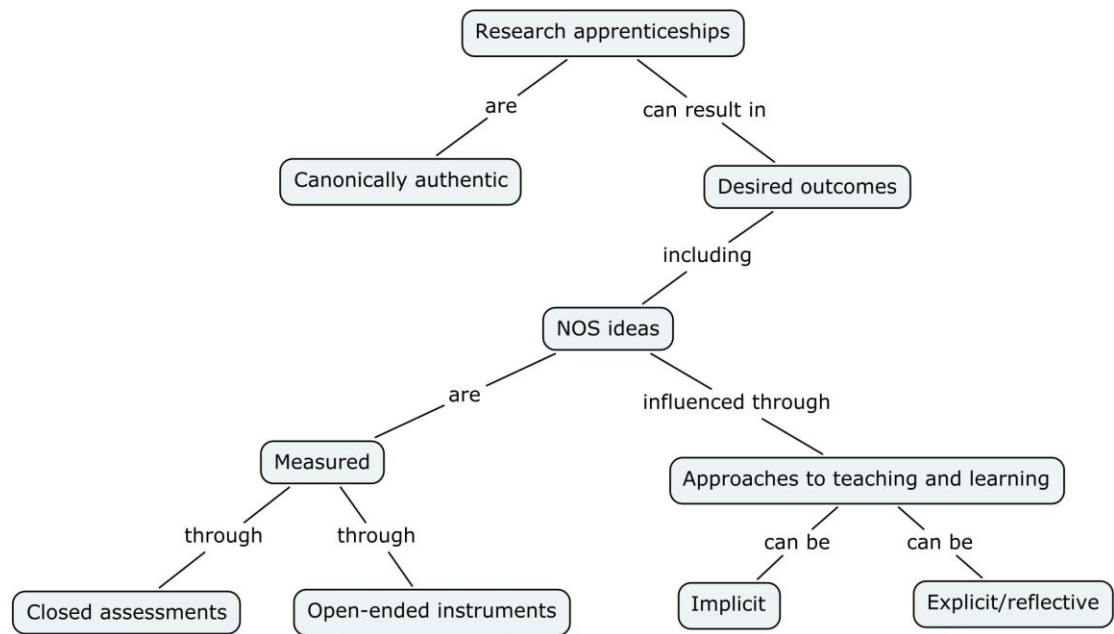


Figure 2-1. Concept map illustrating literature review organization.

CHAPTER 3 METHODOLOGY

Introduction

This study is a naturalistic exploration of the development of secondary student conceptions of Nature of Science (NOS) through participation in authentic scientific research in the context of a research apprenticeship program. A naturalistic inquiry has a number of distinguishing characteristics that relate directly to the features of this study (Lincoln & Guba, 1985). These are that the inquiry is carried out in a natural setting, the use of the human as an instrument, a reliance on tacit knowledge, the use of qualitative methods, the use of purposive sampling, inductive data analysis, the construction of grounded theory, emergent design, negotiated outcomes, the use of case studies, idiographic interpretation, the tentative application of results, focus-determined boundaries and a special criteria for establishing trustworthiness. Table 3-1 presents an example of how each characteristic is represented in this study. Examples of each will be discussed in detail as the chapter unfolds.

The purposes of this study are two fold. The first is to explore the effectiveness of various approaches to the teaching and learning of NOS in the context of a research apprenticeship experience. In general, two such approaches have been described in the science education literature. One of these is an implicit approach in which students are provided with opportunities to conduct scientific inquiries with the assumption that their participation in scientific practices will positively impact their understandings of NOS. The second approach is an explicit approach that is often accompanied by reflection. In this approach, the development of sophisticated understandings of individual aspects of NOS is a specific instructional objective of the designers of an educational experience.

Explicit activities introduce students to these NOS aspects and then students reflect on how these activities and their own experiences in science relate to them. Large numbers of research apprenticeship experiences rely on an implicit approach to NOS teaching and learning (e.g. Barab & Hay, 2001; Bell et al., 2003) and many school science experiences have taken an explicit approach to NOS teaching and learning (e.g. Akerson et al., 2000; Khishfe, 2008). Although there are examples of explicit approaches to the teaching and learning of NOS in the context of research apprenticeships (e.g. Charney et al., 2007; Schwartz et al., 2004), they are very few in number. Additionally, most empirical studies of the merits of these approaches have been single treatment case studies (e.g. Aydeniz et al., 2010; Bell et al., 2003; Khishfe, 2008). The few studies that compare both approaches through a multiple case study methodology (e.g. Khishfe & Abd-El-Khalick, 2002) have been conducted in school science settings rather than in the context of research apprenticeship experiences. Finally, although some studies have examined the role of reflective writing in influencing NOS ideas (e.g. Wagner & Levin, 2007), this has yet to be investigated in the context of a research apprenticeship program. The apprenticeship program investigated in this study has a required seminar component that offers an ideal venue for an investigation of the implicit approach, the explicit approach and the role of reflection in each.

Secondly, other influencing factors in addition to the approaches to NOS teaching and learning outlined above may be related to changes in participant understandings of NOS in the context of research apprenticeship experiences (Burgin et al., 2011). The identification and examination of these other influential factors represents an additional purpose of this study. When examining these factors, students' perceptions of the

nature of their own participation in scientific practices and the degree to which they view this work as overlapping with the work of professional scientists were also investigated as a potential influencing factor. If students believe that their work is aligned with the realm of professional scientific practices, then it would not be unnatural to expect participation in a research apprenticeship program to have a potential influence on participant NOS ideas as revealed on instruments used to gauge their understandings of professional science. This would alleviate some of the problems described by Sandoval (2005) regarding an “assumed coherence of beliefs” (p.11) made by science education researchers between science learners’ conceptions of their own scientific inquiries and their ideas of the knowledge construction that occurs in professional science.

A theoretical framework has been previously described that outlines a possible relationship between participation in authentic science experiences and the degree to which learners’ practical and formal epistemologies of science overlap (Figure 1-1). This theoretical framework provides the context for this study that aims to construct a new, albeit tentative, theory regarding the influential factors within this research apprenticeship experience and their impact on participant NOS ideas. This aim is consistent with the axioms of the naturalistic inquiry paradigm, namely that realities are constructed and multiple rather than the positivistic notion that reality is both single and tangible (Lincoln & Guba, 1985). An application of constructivist grounded theory was the methodology employed as theory was allowed to emerge from the data that were collected in this study (Charmaz, 2006).

The remainder of the chapter is devoted to the methodological considerations of this research study. First the research questions are presented verbatim and discussed. Next, attention is turned to issues of research design. In discussing the design of this study, the setting, the population and sampling and the interventions are described in detail. The stages of data collection and the instruments and strategies that were employed are then presented along the time frame it took to do so. Following this, the phases of data analysis as they relate to providing answers to the research questions guiding this study are outlined. The chapter concludes with a treatment of the criteria of trustworthiness for constructivist grounded theory including issues of credibility, originality, resonance and usefulness (Charmaz, 2006).

Research Questions

Question 1

What are the impacts of various approaches (implicit approach, reflective approach and explicit/reflective approach) to NOS teaching and learning on participants' NOS ideas in the context of a research apprenticeship program?

Sub-question 1a

Do various approaches to NOS teaching and learning result in any significant changes in participants' NOS ideas during the experience?

Sub-question 1b

Are there significant differences in participants' changes in NOS ideas between participants experiencing different approaches to NOS teaching and learning?

Sub-question 1c

How are changes in NOS ideas different for participants experiencing different approaches to NOS teaching and learning?

The first research question and sub-questions examine the influence of three different approaches to the teaching and learning of NOS on student conceptions of NOS. Sub-question 1a drove an investigation of whether or not significant changes in NOS ideas occurred for any of the participants in the study regardless of which approach was used. An exploration of sub-question 1b revealed the extent to which changes in NOS ideas are significantly different among students experiencing the various approaches. Through an examination of sub-question 2c, any differences among the changes in NOS ideas for students experiencing the different approaches could be described in detail.

Question 2

How are participants' NOS ideas influenced by factors within their particular laboratory placements during a research apprenticeship program?

Sub-question 2a

What are the influencing factors that relate to changes in participants' NOS ideas?

Sub-question 2b

How are the influencing factors related to changes in participants' NOS ideas?

The second research question and sub-questions build on the first in that they acknowledge the possibility of additional factors beyond the specific approaches to NOS teaching and learning implemented in seminar settings that may influence the NOS ideas of participants of a research apprenticeship program. It is believed that one of these influencing factors may be the fit between the proposed theoretical framework (Figure 1-1) and the perspectives of the participants in this study. An examination of these perspectives allowed the researcher to make some claims regarding the degree of overlap between participants' formal and practical epistemologies of science

(Sandoval, 2005) and the influence of this relationship on participant NOS ideas. If participant conceptions were truly overlapping, then it was expected that practical work in science might have influenced formal conceptions of science apart from various approaches to the teaching and learning of NOS.

Taken together, the results obtained through an investigation of these research questions was used to construct a theory regarding the experiential aspects that may or may not be influential in the shaping of NOS ideas that accompanied participation in the investigated research apprenticeship program.

Research Design

Attention is now turned to the design of this naturalistic inquiry in order to provide some answers to the questions posed above. Although tempting to think of the following research design as an unchanging set of steps to be followed, it must be remembered that one of the characteristics of naturalistic inquiry is an emergent design. “Indeed the focus of the naturalist should be on adaptation and accommodation. Review, recycling, and change must be central postures” (Lincoln & Guba, 1985, p. 249). The research design presented below evolved from its original form during the data collection and analysis phases of the study. As such, it is significantly different from the a priori research design that was used to plan this study.

Setting

The natural setting for this study was a research apprenticeship program designed for secondary students. This program will be hereafter referred to by the pseudonym the Authentic Experiences in Science Program (AESP). Research apprenticeships have been conceptualized for the purposes of this study as authentic experiences in which participants engage in scientific inquiry in professional settings under the mentorship of

a working scientist or scientists for the purposes of collecting and analyzing data that are of value to the scientific community. The program serving as the context for this study fit the above description of research apprenticeships.

The AESP was a seven-week residential summer experience that was offered at a major research university in the Southeastern United States. This study was conducted in the 53rd year of the program. Eighty-eight qualified rising high school juniors and seniors were accepted for and enrolled in the program. Applicants were accepted on the basis of standardized test scores (e.g. PSAT, ACT), letters of recommendation from two math and/or science teachers and responses to three written essays one of which asked students to describe their interest in science and their long-term career plans. As such, the AESP had been designed for highly achieving and motivated students of math and science. The cost for the program was \$3500 per student. Some scholarship funds were available for students with a demonstrated financial need.

The primary focus of the AESP was on secondary student participation in highly authentic forms of scientific research. Participants worked for a minimum of 28 hours per week conducting scientific research in a research laboratory. Students were placed in laboratories based on their preferred area of scientific interest (e.g. life science, physical science). Once placed, students worked under the direct guidance (mentorship) of a professional scientist or engineer and the graduate students working in their labs. Mentors included faculty and graduate students from the departments of entomology and nematology, food science and human nutrition, periodontology, biomedical engineering, horticultural science, astronomy, biology, chemistry, physics, zoology and medicine among many other departments. Students were immersed in the

everyday activities of a working laboratory within these departments. These activities included participation in laboratory group meetings, researching relevant scientific literature, planning of scientific research, using specialized laboratory equipment to collect and analyze scientific data, writing an experimental research paper, creating a poster summarizing the study and giving an oral presentation of results and findings.

In addition to the research component, participants attended lectures and seminars and participated in research discussion groups with other program participants who were researching similar scientific topics. In fact, all students were required to enroll in an interdisciplinary science seminar course for either dual enrollment credit or on a pass/fail basis. The seminars met twice a week. Past seminar topics have included applied conservation biology, evolutionary genomics, virology and neurobiology. Participants were presented with seminar course titles and descriptions and then ranked their top three choices. AESP personnel tried to accommodate the desires of the participants when making seminar assignments. Eight to ten such seminars are offered annually with an average enrollment of around ten participants in each. Finally, students participated in a number of social and recreational activities that included dances, talent shows, pizza parties, awards banquets and trips to amusement parks.

The administrators of the AESP have a number of stated goals for participants. The program has been “designed to provide challenging and inspiring experiences, to develop leadership qualities, and to stimulate interest in science-related careers” (promotional brochure). Additionally, the administrators stated that participants are provided with “a strong base of knowledge and confidence that they will use throughout

their personal and professional lives” (program annual report). According to these administrators, this knowledge included an understanding of NOS.

Population and Sampling

The participants for this study were drawn from a total population (n=88) enrolled in the AESP during the summer of 2011. Institutional review board informed consent forms were distributed to this total population. Volunteers gave permission to participate in this research study. Since the participants of the study were minors, parental consent was also obtained. From the total population, a subset, consisting of the participants of three specific seminars was identified. The content focus of each of these seminars was a biological science topic examined from a genetics perspective. This helped make for random assignment across the three seminars, as students who enrolled in these seminars were all interested in biological sciences. The difference between these seminars was the approach to NOS teaching and learning employed in each. These three approaches, which will be described below in greater detail, were explicit/reflective, reflective and implicit respectively. Eleven participants were enrolled in the seminar taking an explicit/reflective approach, nine participants were enrolled in the seminar taking a reflective approach and ten participants were enrolled in the seminar taking an implicit approach. This resulted in the purposive selection of 30 participants for inclusion in this study. From these 30 participants, six were identified as case study participants. These case study participants were made up of two representative members of each of the three intervention seminars. Additionally, these case study participants were selected based on the similarities between their laboratory placements, initial NOS ideas, the level of detail of their descriptions of these ideas and demonstrated room for development of these ideas. Also worthy of noting is that out of

the six case study participants, three were placed in a laboratory with another AESP participant and two were recipients of scholarship funding. The approximately 30 participants and the six case study members selected from them were representative of the larger population enrolled in the research apprenticeship program in terms of gender and ethnicity.

Table 3-2 displays the demographic characteristics for these six case study participants, whether or not they were working in partnership with another AESP participant in their laboratory placement, the seminar they were enrolled in, the discipline of their laboratory context and the title of their research project. As can be seen, each of the six participants represents one unique case. Also indicated on this table are the two case study participants who were recipients of scholarship funds. The participants themselves selected the pseudonyms that appear in this table.

The sampling employed in this study was naturalistic for a few reasons. First, Lincoln and Guba (1985) argue that naturalistic sampling should be “based on informational, not statistical considerations” (p.202). Prior to the study, a forecast prediction was made that 30 participants would be included in this study based on an estimate of the average enrollment that could be expected for the three different seminars to be investigated. Although the actual number was 30, it could have been more or less than this number and it would have made no difference to the study itself. Also, the identification of case study participants was completely based on the informational considerations previously described. Additionally, “the criterion invoked to determine when to stop sampling is informational redundancy, not a statistical confidence level” (Lincoln & Guba, 1985, p. 202). As will be described below, the six

case study participants were sampled for follow-up interviews regarding their pre and post-responses to an open-ended questionnaire targeting their NOS ideas. It was believed that informational redundancy would be achieved when comparing these six participant interviews with the questionnaire responses from the entire population.

Interventions

The 30 participants in this study were enrolled in three different seminars each experiencing a different approach to the teaching and learning of NOS in the context of studying a biology-related topic from a genetics perspective. Each seminar met twice a week over the duration of the apprenticeship experience and was co-taught by graduate students of the university hosting the program. Prior to the start of the program, the researcher of this study met with the graduate student instructors of each seminar in a joint planning meeting. During this time, all instructors were informed of the nature of the intervention in each seminar and discussions were held related to how genetics would be the perspective from which each biology-related topic was covered. Observations were conducted periodically in each of the seminars throughout the program to ensure that the interventions were taking place according to plan. The three interventions have been labeled based on the approach that was employed. These approaches are the implicit, the implicit/reflective and the explicit/reflective approaches. Figure 3-1 provides an overview of the three different seminars and the interventions that took place in each. While the seminars were all related in terms of the science content examined, they differed in terms of the reflective opportunities and the introduction to NOS aspects provided to participants.

Table 3-3 describes the interventions experienced by the participants of the three seminars in greater detail with attention given to the time frame of implementing them

during the course of the seven-week AESP. The interventions described in this table will now be discussed in the context of the seminars in which they took place.

Implicit approach

The first seminar from which participants were drawn took an implicit approach to NOS teaching and learning. All of the participants in this seminar simultaneously participated in the authentic research apprenticeship experience. An implicit approach assumes that such participation will influence learner conceptions of NOS (Lederman, 2007; Sadler et al., 2010). This approach is frequently taken in the context of a research apprenticeship program where there seldom is opportunity for explicit instructional design aimed at impacting NOS ideas (e.g. Aydeniz et al., 2010; Bell et al., 2003; Ritchie & Rigano, 1996; Ryder & Leach, 1999). The scientific content investigated in this seminar was related to animal behavior. Reflective opportunities to connect participant understandings of NOS to the work that they were doing in their research lab and an explicit examination of NOS aspects through designed activities and reflective discussions linking NOS aspects to animal behavior were not incorporated in this seminar.

Reflective approach

The second seminar that was investigated utilized a reflective approach. In this seminar, like the first, participants were engaged in authentic forms of scientific inquiry through their research apprenticeship experience. Participation in laboratory work could have possibly impacted participant conceptions of NOS as the result of an implicit approach. The topic of conservation was examined in this seminar from a genetics perspective. Additionally, the participants were provided with individual reflective opportunities. Although some empirical research studies have paired reflective

opportunities with an implicit approach (Barab & Hay, 2001; Bleicher, 1996; Hay & Barab, 2001; Richmond & Kurth, 1999), these studies are few in number and the specific nature of the reflective activities are not clearly elaborated. In this seminar, students responded to reflective journal prompts at the beginning of each meeting. The journal prompts and the time frame for their implementation are provided in Appendix A. They were designed to engage the participants in reflecting on the links between their own participation in scientific practices and Sandoval's (2005) NOS aspects. Such reflection has been described as reflection-on-practice (Schön, 1983; 1987). Participants were provided with composition notebooks with these journal prompts attached. They took approximately ten minutes to respond to each prompt on any given day. Participant notebooks were collected at the end of each seminar session and students were provided with feedback from the researcher following each meeting. This feedback was used to encourage students to reflect deeply on the given prompts. Like the participants of the implicit seminar, the participants of this seminar did not receive any explicit NOS instruction through activities, nor were explicit connections made between NOS aspects and the scientific content being studied in the seminar.

Explicit/reflective approach

The final intervention took place in a seminar utilizing an explicit/reflective approach to NOS teaching and learning. This seminar was co-taught by the researcher of this study. Although this approach has been taken in the context of research apprenticeship experiences (Charney et al., 2007; Schwartz et al., 2004), it is much more common in the context of traditional school settings (e.g. Akerson et al., 2000; Khishfe, 2008; Khishfe & Abd-El-Khalick, 2002; Lotter et al., 2009; Yacoubian & BouJaoude, 2010). Perhaps this is due to the lack of opportunities for explicitly

designed instruction in research apprenticeship experiences as a result of them taking place in non-formal settings. The context of the AESP, like that investigated by Schwartz and colleagues (2004), was rare in that it required participation in content seminars where an explicit/reflective approach could be implemented. Again in this context, as with the previously described seminars, all participants were simultaneously engaged in participation in authentic scientific inquiries. Evolution from a genetics perspective was the focus of the content being investigated in the seminar. The participants were provided with the same individual reflective journal prompts (Appendix A) and given feedback on their responses in the same way that was described when discussing the reflective approach. What distinguished the explicit/reflective seminar from the other seminars were the explicit NOS activities that were used to foster collaborative reflective discussions on NOS aspects as they related to the science topic being examined in the seminar. Many of these activities (e.g. Lederman & Abd-El-Khalick, 1998) have been used by others when implementing an explicit/reflective approach (e.g. Akerson et al., 2000; Akerson & Hanuscin, 2007; Bell et al., 2010, Hanuscin et al., 2006). Table 3-4 lists the NOS activities that were used in the explicit/reflective seminar. Along with their description, the targeted NOS aspects for each are identified. Following participation in explicit NOS activities, an instructor of the seminar (the researcher of this study) engaged the participants in reflective discussions relating various NOS aspects to the topic of evolution from a genetics perspective. Others have successfully implemented similar explicit/reflective approaches to NOS teaching and learning through embedding NOS aspects within a cutting edge science topic (Bell et al., 2010; Khishfe, 2008; Khishfe & Lederman, 2006).

Data Collection

What follows is an overview of the phases of data collection and initial analysis that were conducted during and immediately following the AESP. Table 3-5 provides the time frame for data collection and initial analysis, along with descriptions of the phases of the study and the participants that were involved. The plan outlined here was revised during the process of data collection and analysis. Lincoln and Guba (1985) emphasize that, “it is during the period of data collection and recording (together with initial data analysis) that most design changes will emerge, leading to recycling or extensions of previous steps” (p. 267). Therefore, the design for data collection and initial data analysis presented in Table 3-5 is a modified plan according to the emergent needs of the study as it unfolded. For example, it was originally planned that during week four, the researcher would narrow down the initial case study participants from six to three final case study participants. However, observations, field notes and interviews continued with the six initial case study participants for the duration of the program.

Ideas about Science Survey (ISS)

The design outlined in Table 3-5 made use of an open-ended NOS questionnaire, the Ideas about Science Survey (ISS) (Appendix B), administered to participants of the study at the beginning of the AESP and again at its conclusion to document potential changes in participant NOS ideas. Others have used open-ended questionnaires in a similar pre-post methodological design to investigate the impact of various approaches to NOS teaching and learning in a variety of settings (e.g. Akerson & Hanuscin, 2007; Akerson & Volrich, 2006; Bell et al., 2003; Hanuscin et al., 2006; Khishfe & Abd-El-Khalick, 2002; Schwartz et al., 2007; Yacoubian & BouJaoude; Yen & Huang, 1998).

The use of open-ended questionnaires to assess conceptions of NOS is a relatively modern development in the history of science education research on NOS (Lederman et al., 1998; Lederman, 2007). From the 1950s through the mid-1990s assessment of learner NOS ideas was accomplished primarily through the use of quantitative instruments such as the Test on Understanding Science (Cooley & Klopfer, 1963) and the Nature of Scientific Knowledge Scale (Rubba & Anderson, 1978). These instruments are representative of others that made use of multiple choice questions and Likert-scale items to gauge student comprehension of the philosophy and epistemology of scientific knowledge. Some critiques have been made of such quantitative measures of NOS ideas (Lederman et al., 1998). One such critique deals with the scoring of the instruments themselves. When student choices are marked as right or wrong, the students' understandings are being described as either aligning with or against the perspectives of the developers of the instrument itself. At the time of the construction of these instruments, a Popperian (Popper, 1959) view of NOS with its emphasis on the approximation of truth dominated the philosophy of science. Since then, views of NOS have shifted to more Kuhnian (Kuhn, 1962) perspectives of the social construction of scientific knowledge and scientific revolutions resulting from paradigm shifts. As such, what would have been scored as correct at the time of the development of these instruments could possibly be scored as incorrect today. As a result of this critique and others like it, "it is suggested that the current educational research shift toward more qualitative, open-ended approaches to assessment of individuals' understanding (of any concept) be applied to the assessment of individual's nature of science conceptions" (Lederman et al., 1998, p. 595).

To this end, open-ended questionnaires paired with follow-up interviews have been developed in order to allow students to express their own perspectives regarding their NOS ideas. Among the most widely used open-ended NOS questionnaires is the Views of the Nature of Science Questionnaire (VNOS) (Lederman et al., 2002). This questionnaire elicits learner perspectives regarding the empirical nature of scientific knowledge, scientific theories and laws, 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 the scientific method and the tentative nature of scientific knowledge. As has previously been discussed, these seven aspects can be collapsed within Sandoval's (2005) four aspects of scientific epistemology. The first version of this instrument, the VNOS-A, was developed by Lederman and O'Malley (1990) in response to the problems inherent to forced-choice quantitative NOS measures. However, even these open-ended assessment instruments are not free from criticism. For example, Lederman and O'Malley (1990) documented differences between their interpretations of participant responses and participant descriptions of their own responses as indicated through follow-up interviews. This demonstrated the need for follow-up interviews in conjunction with the VNOS. Abd-El-Khalick, Bell and Lederman (1998) further modified the VNOS into a second version, the VNOS-B. Initially all participants were interviewed to elicit their feedback regarding their responses to the VNOS-B items. Over time, using the VNOS-B to elicit the NOS perspectives of preservice science teachers in a number of studies, it became evident that it was unnecessary to interview all participants.

As the researchers became more cognizant of the meanings that participants ascribed to key terms and phrases, and developed more

expertise in interpreting participants' responses, it was apparent that it was not imperative to interview all participants after administrations of the VNOS-B. Depending on the sample size, the researchers were now obtaining redundant meanings, categories, and themes (Lincoln & Guba, 1985) from interviews with 15-20% of participants. (Lederman et al., 2002, p.505)

The construct validity of the VNOS-B was also established by comparing the differences in the interpretations of the responses made by an expert group of learners who held sophisticated NOS understandings and a group of learners who held NOS ideas that differed from consensus understandings of NOS (Bell, 1999). The results of this effort "lent strong support to the construct validity of the VNOS-B" (Lederman et al., 2002, p. 507). Other versions of the VNOS have also been established. The VNOS-C (Abd-El-Khalick, 1998) was developed to gain further insight into respondents' perspectives of the social and cultural embeddedness of science and the myth of the scientific method. The VNOS-D (Lederman & Khishfe, 2002) was tailored to meet the needs of middle school and elementary school learners. This document has been further modified into the VNOS-D+ which is more suited to secondary learners in particular.

For the purposes of this study, the ISS was constructed (Appendix B). This survey consists predominately of items from the VNOS-D+ with a handful of items from the VNOS-C (items 12 and 14), an item from the VNOS-B (item 9) and two items (items 3 and 8) written by the researcher. This survey was selected as the instrument of data collection for eliciting participant perspectives of NOS. This decision was made for a few reasons. First, the VNOS-B (which is very similar to the VNOS-D+) has been used before to collect data from secondary students in the context of a research apprenticeship (Bell et al., 2003). Secondly, the VNOS-D+ was estimated to take 35-45 minutes for a participant to complete compared with an estimated 45-60 minutes for

completion of the VNOS-C (Lederman et al., 2002). Given the limited time frame for administration of the survey during a 50-minute seminar, relying heavily on the VNOS-D+ items was logical in this context. Thirdly, the items of the VNOS-D+ are easily comprehensible and readily relate to Sandoval's (2005) NOS aspects that were targeted in the explicit/reflective seminar. Finally, through correspondence with the developer of the VNOS-D+, this instrument was identified as being the most appropriate for this study.

Student participants initially responded to the survey in the first week of the research apprenticeship experience (Table 3-5). As per the recommendation made by Lederman and colleagues (2002), six of the 30 participants in this study (20%) were selected for follow-up interviews regarding their initial responses to the survey. The six students interviewed were the six case study participants whose selection criterion is explained below. These follow-up, semi-structured interviews were used to establish some credibility regarding the researcher's interpretations of participant responses. As such, an interview protocol (Appendix B) was used to allow participants to elaborate on their responses to individual items from the survey. This interview protocol was drawn from the works of Abd-El-Khalick (1998) and Bell and colleagues (2003).

The participant pre-experience written responses to the survey were in part used to identify the six case study participants. The criterion for this identification is presented in the following section. This identification required an initial analysis of participant science survey responses. During this analysis, students' responses were rated as either naïve, a mixture of responses, informed or unknown for each of Sandoval's (2005) NOS aspects. Naïve responses were those that did not conform to current

consensus understandings of NOS by stakeholders in science education, and informed responses were those that did. Responses rated as “mixture” were those that had elements of both naïve and informed responses. This initial analysis process will be described in greater detail in the data analysis section of the chapter.

Finally, the survey was administered again to all of the 30 participants during the sixth week of the program (Table 3-5). Again, the six case study participants were purposively interviewed for clarification regarding their final written survey responses.

Case studies

Six evaluative case studies that included two participants from each of the three intervention seminars were constructed as part of this research study. Lincoln and Guba (1985) describe evaluative case studies as judgmental descriptions that are built from both factual information and interpretations of those realities. The case studies are evaluative in that they attempt to offer some explanation of the factors influencing these participants’ understandings of NOS. Such an explanation requires a level of judgment on the part of the researcher. Figure 3-2 presents the data sources that were used to construct these final case study reports. As can be seen from this figure, survey data, interviews and observations were the data sources employed in telling the stories for the six participants.

“While more conventional paper-and-pencil or brass instrumentation [e.g. the ISS] may be used in naturalistic inquiry...the preponderantly used instrument is the human being” (Lincoln & Guba, 1985, p. 266). Lincoln and Guba (1985) discuss sources of data collected by the human instrument. These sources include interviews and/or observations in addition to “nonverbal cues that are transmitted while those interviews or observations are under way” (Lincoln & Guba, 1985, p. 267). As can be seen in

Figure 3-2, while conventional NOS questionnaires were included data sources for the six case studies, both interviews and observations as human sources of data were major components of the case studies. Additionally, interviews and observations lend themselves to the collection of rich information that is ideal for the construction of grounded theory (Charmaz, 2006).

The ISS, as described above, was used to identify six case study participants (two from each intervention seminar) that had similar initial conceptions of NOS ideas and that all exhibited room for growth. Additionally, these six participants were working in laboratories that were conducting bench-top scientific research on non-human samples (Table 3-2). This criterion excluded participants working on computer engineering or medical research projects. Another factor that distinguished these participants was that half of them were working with another program participant in their laboratory placement (Table 3-2). Over the duration of the AESP (Table 3-5) semi-structured interviews and observations of laboratory work were conducted with the six case study participants. The remainder of this section will focus on the interviews and observations collected by the human as instrument from the six case study participants over the entire research apprenticeship experience.

Sources of data for the case study participants included semi-structured interviews conducted multiple times throughout the apprenticeship. These participants were interviewed every two weeks during the experience for a total of three interviews from each. All interviews were audio-recorded and subsequently transcribed verbatim. Semi-structured interview protocols for the three interviews are located in Appendix C. The purpose of the interviews was not to collect data on students' NOS ideas as was the

purpose of the ISS, but rather to arrive at a deeper understanding of the participants' perceptions of the apprenticeship experience itself in the laboratory setting and its influencing factors on their conceptions of NOS. The questions on the protocols were designed to be open-ended in order to allow for unexpected responses. "By creating open-ended, non-judgmental questions, you encourage unanticipated statements and stories to emerge" (Charmaz, 2006, p. 26). At the same time, however, previous research (Burgin et al., 2011) guided the design of some questions in order to specifically elicit student perspectives about the collaboration experienced in the laboratory (including conversations between the participant and their mentor), their interest in their research, their epistemic involvement in the design of their project and their self-positioning as a researcher in the laboratory. The four experiential factors mentioned above were selected for specific investigation in that they might possibly be related to the development of NOS ideas in the context of authentic experiences in science (Burgin et al., 2011; Ryder & Leach, 1999). The tension between structuring the interview in order to steer the conversation down intended paths and allowing it to flow according to the direction initiated by the participants is one that is inherent to grounded theory in general and this study in particular. "Both grounded theory methods and intensive interviewing are open-ended but directed, shaped yet emergent, and paced yet flexible approaches" (Charmaz, 2006, p. 28). Therefore, the interview protocols (Appendix C) utilized here were purposively designed, yet open to revision during the collection of data. For example, information gained from the participants during the first interview was used to shape and modify the questions on the second interview protocol.

Observational data were also a key component of constructing the case study reports. The six case study participants were observed once a week for six weeks in their laboratory settings. Spradley (1980) refers to the ethnographic researcher conducting observations as a participant observer. He then classifies these observations along a continuum of participation ranging from nonparticipation to complete participation. The observations for this study were exemplary of passive observations (Spradley, 1980). In this type of observation, the participant observer does not take place in the normal activities of the culture that he or she is observing, but does form relationships with those being observed through interviews and conversations. Appendix D contains the observational protocol that was used during the six weekly observations. Observations lasted approximately one hour each. The researcher took detailed field notes of all laboratory activities and conversations during these observations. Similarly to the semi-structured interview protocols, the observational protocol was intentionally designed to encourage the observer to be aware of instances indicative of certain experiential factors within the laboratory setting that may be related to the development of NOS ideas. According to Charmaz (2006), “grounded theory ethnography [like the observational data to be collected in this study] gives priority to the studied *phenomenon* or *process*- rather than the setting itself” (p. 22). Therefore, the observational protocol was designed in order to prioritize the phenomenon of “science in practice” rather than recording all of the nuances of the laboratory setting. For example, the researcher looked specifically for engagement on the part of the case study participant as scientific research was being conducted. This included instances of collaboration and epistemic involvement on the part of the participant. Additionally, the

researcher looked for and recorded any and all nonverbal cues that may have indicated interest, involvement and positioning on the part of the case study participant. Finally, as with the interview protocols, the observation protocol was modified during initial data analysis to account for emerging trends as data were being collected.

In conclusion, survey data accompanied by interview and observational data were used to construct detailed pictures of six different participants in the AESP. Each of the participants represented a unique case in that some were working with another program participant, all experienced one of three different intervention seminars and all were placed in a unique laboratory setting with different mentor scientists. The rich stories told for the case study participants present an account of the multiple factors (including but not limited to the intervention seminars) and their influence on the development of participant NOS ideas. Lincoln and Guba (1985) summarize the merits of a case study approach best when they say:

The case study builds on the reader's tacit knowledge, presenting a holistic and lifelike description that is like those that the readers normally encounter in their experiencing of the world, rather than being mere symbolic abstractions of such. Readers thus receive a measure of vicarious experience; were they to be magically set down in the context of the inquiry they would have a feeling of déjà vu. (p. 359)

Mentor interviews

One additional source of data that was collected warrants discussion in this section. That was the interviewing of the mentors of case study participants. The semi-structured interview protocol that was used to collect information related to mentor perspectives is found in Appendix E. Shortly following the conclusion of the AESP, the mentors of the six case study participants were interviewed. This resulted in 12 interviews as each participant was mentored both by a science faculty member and a

graduate student working in their lab. The purpose of the interviews was to elicit mentor perspectives of the NOS idea changes that they believed to have occurred among the participants placed in their laboratories and the factors that they believed were influential in that developmental process. Mentor perspectives were used to lend some credibility to observational data and participant self-reported interview data.

Data Analysis

ISS analysis

The analysis of research question one and sub-questions, in addition to at least part of the analysis of research question two and sub-questions, required an interpretation of data obtained through two administrations of the ISS to the 30 participants in this study. Comparisons of responses on the survey given at the beginning of the research apprenticeship with those given at the end of the program allowed the researcher to make some claims regarding the changes in NOS understandings that occurred during the experience. It was these changes, which may or may not have represented positive gains in NOS understandings, which were used to evaluate the effectiveness of the three different approaches under investigation in the first research question and sub-questions. Additionally, in order to investigate the influencing factors on these NOS ideas for the case study participants, it was important to understand how their understandings changed over the seven-week apprenticeship program.

The analysis of the participant responses to the survey was guided by the recommendations of the developers of the instrument (Lederman et al., 2002). Student responses to the survey items were rated as either naïve, mixed, informed or unknown by the researcher in regard to the NOS aspect or aspects that were targeted by each

item. Such an analysis was representative of typological data analysis in that a-priori categories were employed as surveys were analyzed (Hatch, 2002). It is worth mentioning here that the items on the ISS do not correspond directly with these NOS aspects in a one to one manner. From a quick perusal of the survey (Appendix B), one can see that many individual questions relate to more than one of Sandoval's (2005) NOS aspects.

Ratings of either naïve, mixed, informed or unknown were made based on the degree to which students' understandings of NOS aligned with or did not align with current consensus understandings of NOS by a variety of stakeholders in science education. The illustrative examples of questionnaire responses provided by the developers of the instrument helped guide the researcher through the analysis process (Lederman et al., 2002). When assigning these ratings, the researcher made all efforts to keep the level of inference low. The survey was designed in such a way that the interpreter need not attempt to over analyze the responses of individual participants (Lederman et al., 2002) when assigning ratings.

A lengthy process was used to establish the trustworthiness of these ratings. First, a second interpreter who has worked with the researcher before in analyzing NOS survey data in the context of this program independently analyzed ten of the sixty surveys at random. An inter-rater consistency of 64% was established and the raters discussed their disagreements. Due to this low percentage, a second round of analysis was conducted where the raters separately analyzed ten more surveys. This time, an inter-rater consistency of 60% was established. The raters then discussed how they felt that this low level of consistency was due to force-fitting the data from a questionnaire

designed to assess the Lederman et al. (2002) NOS aspects into Sandoval's (2005) epistemology schematic. The researcher then reexamined the Lederman et al. (2002) NOS themes and constructed a new coding rubric based on these aspects rather than Sandoval's epistemological themes. This new coding rubric is provided in Appendix F. This coding rubric contains seven Lederman et al. (2002) aspects and one Sandoval (2005) aspect. The Sandoval aspect that remained was that scientific knowledge is constructed. A third round of analysis was conducted using this new rubric with the same ten surveys used in the second round and an inter-rater consistency of 82.5% was calculated between the two raters. The raters then met to discuss and recognized some coding error. When this coding error was accounted for, the consistency increased to 96.3%. This process helped the researcher to recognize the importance of a second set of eyes to reduce rater error and help build trustworthiness. As a result, a third rater, one of the co-instructors of the explicit/reflective seminar, along with the researcher independently rated each of the remaining fifty surveys. These two raters talked through any discrepancies and reached 100% consensus on their ratings for each of the surveys.

Profiles of NOS ideas were then created for each student (n=30). The profiles displayed the rating (naïve, mixed, informed or unknown) for each Lederman et al. (2002) NOS aspect in addition to the Sandoval (2005) aspect that scientific knowledge is constructed at the beginning and at the end of the research apprenticeship experience as revealed through the questionnaire. Claims could then be made from an analysis of the profiles regarding the changes in participant NOS understandings that occurred during the experience.

Once these profiles were created, the change in NOS ideas was examined according to categorical methods of statistical data analysis. First, a Kruskal-Wallis/Wilcoxon Rank Sum analysis was used to test for any significant differences in changes in NOS ideas between the members of the different intervention seminars. Secondly, a McNemar analysis was employed to account for which NOS aspects were showing significant changes for which intervention seminar. The decision to employ a McNemar analysis emerged during the data analysis process.

Following this categorical data analysis of the open-ended science questionnaire, the same two researchers that conducted the majority of that analysis examined the survey interviews conducted with the six case study participants. The surveys were coded for each of the previously discussed NOS aspects and students were rated as having naïve, informed, unknown or a mixture of views regarding each. Such an analysis can be regarded as a typological data analysis of interview data (Hatch, 2002) as coding categories had been previously identified. The two researchers analyzed four of twelve total pre and post survey interviews with the six case study participants independently. The consistency between their ratings was established to be 97%. The first researcher then independently analyzed the remaining eight survey interviews. Comparisons were then made between the NOS understandings of the case study participants as revealed on the written surveys and as revealed through the survey interviews.

Application of constructivist grounded theory

The second research question was investigated primarily through an application of a constructivist grounded theory approach to data analysis (Charmaz, 2006). Through this approach, emergent theories were co-constructed by researchers and participants

through interpretations of multiple realities. According to Charmaz (2005), “our conceptual categories [in constructivist grounded theory] arise through our interpretations of data rather than emanating from them or from our methodological practices. Thus, our theoretical analyses are interpretive renderings of a reality, not objective reportings of it” (p. 510). The above description aligns nicely with the axioms of naturalistic inquiry (Lincoln & Guba, 1985) that stand in stark contrast to the positivist notion of a single objective reality.

The constructivist grounded theory approach was utilized to analyze the data collected with the six case study participants in an effort to understand influencing factors on their NOS understandings. The first step of the process involved initial coding of the first semi-structured interviews and observations conducted with the six case study participants. All coding for this study was done using the software program HyperRESEARCH. This initial coding was guided by a hybrid use of typological analysis (Hatch, 2002) and the methods recommended by Charmaz (2006). According to Hatch (2002), typological analysis begins by “dividing the overall data set into categories or groups based on predetermined typologies” (p. 152). These typologies “are generated from theory, common sense, and/or research objectives” (Hatch, 2002, p. 152). Some typologies that were employed in this study included insider/outsider feelings, relationships in the lab, collaboration, comfort in the laboratory setting, epistemic involvement, interest in the research project and understanding of the research project’s value. An application of constructivist initial coding was used in addition to the typological coding described above to allow for additional emergent codes that described factors that may have influenced participant NOS understandings. Initial

coding in constructivist grounded theory does not arise from predetermined categories but rather emerges from the data. A hybrid use of typological analysis and constructivist initial coding does not seem to conflict with the description of coding given by Charmaz (2006). "I agree with [the] approach of keeping initial coding open-ended yet acknowledge that researchers hold prior ideas" (Charmaz, 2006, p. 48). The initial coding guiding the analysis of interview data occurred line-by-line from the verbatim transcriptions of those data sources, whereas the initial coding of the observation field notes was incident to incident as determined by the researcher. In vivo codes (the use of participant language to determine the naming of codes) were used wherever applicable. They were used when they provided a unique and/or rich description of the data in question. This process resulted in 188 initial codes.

Once initial coding was completed, a second round of focused coding further refined the categories that were emerging in addition to those that were predetermined. During this process, only the relevant initial codes remained as redundant or irrelevant codes were deleted. The categories directly related to the factors that both the researcher and the participants believed to be influencing participant NOS understandings. The result was 121 focused codes. This process relied on the constant comparative method (Glaser & Strauss, 1967) where codes were compared both across multiple participants and within multiple data sources from the same participant. Throughout the analysis, the researcher recorded detailed memos outlining the initial and focused coding processes.

A final stage of theoretical coding was conducted in which focused codes were organized into related themes or theoretical codes. Three main theoretical codes

emerged from this analysis. These codes were authentic action, being treated authentically and feelings of authenticity. Example codes from each of these three phases of the constructivist grounded theory coding process can be found in Table 3-6.

Following an initial analysis of the first interviews and observations, theoretical sampling was conducted. Theoretical sampling is a process of purposeful data collection based on the emergent understandings from the early stages of constructivist grounded theory analysis. In this study, preliminary results from the first interviews and observations were used to modify subsequent interview protocols in order to collect further data on NOS influencing factors that were beginning to emerge. The theoretical sampling described here very much coincides with notions of emergent design that typify naturalistic inquiries of this sort (Lincoln & Guba, 1985).

The end result of the constructivist grounded theory was an interpretive theory that accounted for the data collected and provided an answer to the questions guiding the research. "Interpretive theory calls for the imaginative understanding of the studied phenomenon. This type of theory assumes emergent, multiple realities; indeterminacy; facts and values as linked; truth as provisional; and social life as processual" (Charmaz, 2006, p. 126). The emergent theory achieved through this study described the influencing factors on the case study participants' understandings of NOS. The influencing factors emerged through co-constructed multiple realities that took into account the perspectives and values of both the participants and the researcher.

Criteria for Trustworthiness

Lincoln and Guba (1985) discuss the importance of establishing trustworthiness in the results of naturalistic inquiries. They describe a number of criteria for establishing this trustworthiness. These are the credibility, transferability, dependability and

confirmability of naturalistic inquiry findings. The criteria are used to persuade the reader of the value of findings. Charmaz (2006) has a very similar list of criteria for use in constructivist grounded theory in establishing trustworthiness. Since much of the analysis of research question two relied on the methods of constructivist grounded theory, these criteria were used for this study. This list includes the credibility, originality, resonance and usefulness of the findings. Each of these criteria will now be discussed in turn.

Credibility

The credibility of this research study is based largely upon the quantity and quality of the data from which understandings emerged. The data collected were very detailed and revealed a rich picture of the research apprenticeship program and the various laboratory settings within it. The emergent categories covered wide ranges of data and demonstrated that a redundancy in sampling (Lincoln & Guba, 1985) had been reached. All claims were logically linked to the data in such a way that an independent reader would likely reach the same conclusions as the researcher. Additionally, the use of assessment items from a previously validated open-ended instrument (the VNOS-D+) when making claims about NOS idea changes that occurred during the program, lent a greater amount of credibility to such claims than would have an over-reliance on self-reported interview data to establish participant NOS understandings.

Originality

This research is truly original in that it offers new insights into the factors that influence participant NOS ideas in the context of a research apprenticeship program. Such a systematic comparison of various approaches to NOS teaching and learning had yet to be conducted in this setting and therefore resulted in original understandings.

This work has significance from both a theoretical and a practical perspective.

Theoretically, this research challenges the current understandings of the power of authenticity in influencing NOS understandings through an implicit approach. Practically, the emergent influencing factors have the potential to inform the design of future research apprenticeship experiences in novel ways.

Resonance

This research revealed taken-for-granted meanings within the research apprenticeship experience. Links were made between the larger research apprenticeship program and the seminar interventions and individual laboratory experiences within it. Importantly, the meanings and links resonated with the participants of this study. Lincoln and Guba (1985) argue that the outcomes of a naturalistic inquiry should be negotiated between the participants and the researcher both throughout the inquiry and upon its conclusion. Throughout this inquiry, member checking was conducted with the case study participants in a few different ways. First, during the early rounds of interviews and observations, the case study participants were asked for clarification of responses and were asked if they agreed with the initial interpretations of the researcher. Finally, upon completion of the data analysis, the six case study participants and their mentors were provided with an overview of the results in order to check for agreement and that the researcher's interpretations made sense to them.

Usefulness

The results of this research are useful in a number of ways. First, the interpretation of the data is informative to the designers of this specific research apprenticeship program. Results offer suggestions for ideal laboratory placements and seminar

interventions aimed at influencing participant NOS ideas. Secondly, the results contribute to an understanding of the various teaching and learning approaches and factors that influence learner NOS ideas in authentic science contexts. Such knowledge is currently limited in the science education literature base (Chapter 2). Thirdly, the results of the research are useful in that future research questions were constructed regarding specific influential factors on NOS ideas in the context of research apprenticeship experiences. Finally, the results hold some implications for formal school science. Namely, they offer some explanation for why an implicit approach seems to be so ineffective in influence learner NOS ideas in an inauthentic context (Chapter 2). What results is a rationale for the inclusion of more highly authentic experiences in formal school science.

Subjectivity Statement

The role of values is one of Lincoln and Guba's (1985) axioms of naturalistic inquiries. From their perspective, all inquiry is value-bound rather than value-free. They discuss how the values of the researcher influence all aspects of the design of a naturalistic inquiry from the shaping of a problem to the choice of paradigm and substantive theory guiding the data collection and analysis. Related to this is the utilization of tacit knowledge as a characteristic of naturalistic inquiry (Table 3-1). Peshkin (1988) refers to the above as the subjectivity of the researcher and recommends that all naturalistic inquirers explicitly identify their values prior to conducting a research study. This is because the personal qualities that make up a researcher's values "have the capacity to filter, skew, shape, block, transform, construe, and misconstrue what transpires from the outset of a research project to its culmination" (Peshkin, 1988, p. 17). For this reason, the drafting of a subjectivity statement by the

researcher is desirable in that it can allow the researcher to “manage” his biases and “to proclude it [the researcher’s subjectivity] from being unwittingly burdensome” (Peshkin, 1988, p.20). I will now attempt to unburden myself as I discuss the values that I brought to this research study. The discussion will be organized into three parts; my views regarding the participants in this study, my beliefs about authenticity in school science and my understandings of the research apprenticeship program.

I brought with me to this study my values regarding the students that were participants. In view of my experiences as a high school chemistry teacher of advanced upper level secondary students I had pre-conceived notions of the type of student that would volunteer for participation in this study. I believed that these participants would be highly gifted, motivated and highly achieving students. I believed that they would have had a great deal of parental support throughout their educational career thus far. I believed that they would have highly sophisticated understandings of scientific content knowledge. That being said, I believed that, in general, their understandings of NOS would be rather naïve as they entered the research apprenticeship experience. I thought that they would hold the perspective that scientific knowledge is discovered rather than socially constructed by a community of scientists. I believed that they would hold on to the myth of the scientific method as being the only way to conduct scientific investigations. I also believed that many of them would believe in a hierarchical relationship between various forms of scientific knowledge. Finally I believed that they would have understandings that scientific knowledge is absolute and unchanging. These beliefs are backed by the NOS literature (Lederman, 1992; 2007). My subjectivity in this regard likely influenced how I interpreted participants’ initial responses to the ISS.

I also had values regarding the levels of authenticity in both school science and research apprenticeship experiences. In my experiences as a high school chemistry teacher and as a high school student myself, I witnessed first hand how inauthentic school science inquiries can be. The instructor often tightly controls these experiences. Questions and protocols are provided to students as they attempt to verify scientific content that they have previously encountered. Very rarely are students provided with opportunities to explore their own questions and answer them through creative ways in open-ended inquiry experiences in school settings. This is contrasted with the highly canonically authentic experiences that I believe are provided to students through research apprenticeship experiences where the data that they collect and interpret are valuable to the scientific community.

Finally, I have personal experiences with this particular research apprenticeship program that have influenced the design of this study and the data collection and analysis procedures that I employed. Over the past four summers, I have been investigating the AESP and have published research reports regarding the experiential factors and related outcomes of participation in it (Burgin et al., 2011). I believed that the most important aspects of this experience were collaboration in a laboratory community and interest in the research project itself. I also did not think that epistemic involvement was as important as other researchers believe it to be in impacting participant NOS ideas (e.g. Ryder & Leach, 1999). I have therefore designed this study to allow for further investigation of these constructs while at the same time allowing for additional experiential factors to emerge. Additionally, I believed that by participating in

highly authentic forms of scientific inquiry, student understandings of NOS had the potential to be impacted through an implicit approach.

The above subjectivity statement discloses my values that may have impacted this research project from its design and initiation to completion. I agree with Lincoln and Guba (1985) that the main instrument in a naturalistic inquiry is the human instrument and that my values outlined above interacted with those of the participants as knowledge was co-created. The interpretative theory (Charmaz, 2006) that resulted from this research study was likely influenced by my personal perspectives. I therefore do not shy away from my personal values, but rather acknowledge them, embrace them and account for them.

Summary

This study sought to investigate the development of participant perspectives of NOS ideas as an outcome of an authentic scientific research experience and the factors that may have influenced those ideas. Influencing factors could have included various levels of supported participation in content seminars that took different approaches to the teaching and learning of NOS. The different approaches investigated here were the implicit approach, the reflective approach and the explicit/reflective approach. Additionally, this study was designed to allow for additional influencing factors to be identified that were present in the experience outside of the seminar settings.

The design of data collection and analysis procedures for this study was informed by a naturalistic inquiry paradigm (Lincoln & Guba, 1985). As such, qualitative methodologies were employed. Participants of three different seminars responded to an open-ended questionnaire (the ISS) at the beginning and the end of their experience. Their responses were labeled as being representative of either naïve, informed,

unknown or a mixture of understandings of various NOS aspects. Initial NOS understandings that emerged from analysis of the questionnaire responses were used to purposively select six case study participants. The case study participants were systematically interviewed and observed in their natural laboratory setting. Through an application of constructivist grounded theory (Charmaz, 2006) a highly detailed description of the experiences of the case study participants was constructed. From these descriptions emerged an understanding of the various influencing factors on the development of the case study participants' NOS ideas.

The results of this study are useful in that they extend the knowledge base related to how NOS ideas are influenced in the context of research apprenticeships. The resulting understandings will inform the future design of seminars and the identification of ideal laboratory placements for this particular research apprenticeship experience. Additionally, the findings inform the development of other research apprenticeship programs. Finally, an examination of the impact of participation in authentic science on learner's NOS ideas holds implications for school settings. It provides evidence for why an implicit approach to NOS teaching and learning in formal settings seems to be ineffective (e.g. Khishfe & Abd-El-Khalick, 2002) and further provides a rationale for including more authentic forms of scientific inquiry in the context of school science.

Table 3-1. Characteristics of naturalistic inquiry (Lincoln & Guba, 1985)

Characteristic	Example(s) from current research study
Natural setting	Study conducted in the context of a research apprenticeship program and attempts to take into account multiple influencing factors on participants NOS ideas in that setting.
Human instrument	Semi-structured interviews with case study participants allow for the exploration of unexpected responses. Ethnographic observations of participants engagement in “science in practice”
Tacit knowledge	The researcher has experience investigating this apprenticeship program and therefore the intuitive knowledge and values of the researcher will be taken into account.
Qualitative methods	Methodology employed includes open-ended questionnaires, interviews, and observation field notes as sources of data.
Purposive sampling	Participants and sampling based on both informational purposes and the achievement of redundancy. i.e. Number of follow-up interviews and case study participants
Inductive data analysis	Interview transcripts and observational field notes will be coded through use of a constant and comparative method (Glaser & Strauss, 1967).
Grounded theory	Application of constructivist grounded theory in answering research questions (Charmaz, 2006)
Emergent design	Observational field notes will be allowed to inform the design of semi-structured interview protocols.
Negotiated outcomes	Follow-up interviews based on open-ended questionnaire responses. Follow-up interviews with mentors. Member-checking with case study participants throughout and upon completion of the research apprenticeship program.
Case study reporting mode	Reporting of findings from three case study participants in a case reporting format.
Idiographic interpretation	Interpretations will be made based on the individual factors of particular cases including the values of the researcher and the relationships between the researcher and the participants.
Tentative application	The study will have limited implications regarding the potential transferability of these results to the contexts of other research apprenticeship programs.
Focus-determined boundaries	The factors that influence participant understandings of NOS in the context of research apprenticeship programs (a focus of this study) will be bounded by their emergence during data collection.
Special criteria for trustworthiness	A substitute criterion for internal and external validity, reliability, and objectivity will be used to establish trustworthiness for this study.

Table 3-2. Case study participants

Participant	Gender	Ethnicity	Paired	Seminar	Discipline	Research Project Title
3. Jennifer	F	White	Yes	E/R	Biology	Evolutionary Development of Epiascidiate Leaves in <i>Nepenthes alata</i>
4. Jane	F	Asian Indian	No	E/R	Chemistry	Adenylation Domain's Role in Finding Amino Acid, Nonribosomal Protein Synthetase Combinations
*15. Isabel	F	Hispanic	Yes	R	Forest Pathology	Location of <i>Raffaelea lauricola</i> in Redbay trees
18. Joseph	M	African American	No	R	Materials Engineering	Self-assembly of Silica Particle Monolayers using the Langmuir-Blodgett Method at Lower Temperature
*24. John	M	Hispanic	Yes	I	Biology	Different Nest Architecture Results in Changes in Interactions Between Parents but not Parental Care
27. Tom	M	Hispanic	No	I	Chemistry	SPREE Analysis of Protein-Lipid Interactions as a Function of pH

Participant: Scholarship Recipient (*)

Paired: Working with another program participant in the same laboratory placement

Seminar Enrollment: Explicit/Reflective (E/R), Reflective (R), Implicit (I)

Table 3-3. NOS interventions

Time frame	Interventions	Participants
Weeks 1-7	Research Apprenticeship Experience	All participants from all seminars (n=30)
Weeks 2-6	Reflective writings (Responses to journal prompts. Appendix A)	All participants from reflective and explicit/reflective seminars (n=20)
Weeks 2-6	Explicit NOS activities with reflective discussions (Table 3-3)	All participants from explicit/reflective seminar (n=11)

Table 3-4. Explicit NOS activities and targeted NOS aspects used in the explicit/reflective seminar

NOS activity	Description	Target NOS aspect(s) (Sandoval, 2005)
NOS card sort (Cobern & Loving, 1998)	Groups of students are given a set of cards with NOS statements on them. They then refine this set through a series of trades to arrive at a group of cards that is representative of their perspectives.	Construction of scientific knowledge, the diversity of scientific methods, the different forms of scientific knowledge, scientific knowledge varies in certainty
Pictures (Young? Old?; Duck? Rabbit?; The aging president) (Lederman & Abd-El-Khalick, 1998)	Students look at pictures that have multiple interpretations and describe what they see.	Construction of scientific knowledge, scientific knowledge varies in certainty
The cube activity (Lederman & Abd-El-Khalick, 1998)	Students are given a cube and have to guess what is on the bottom of the cube without looking at it based on patterns that they observe.	Construction of scientific knowledge, scientific knowledge varies in certainty
Black box activities (The tube; The water-making machine) (Lederman & Abd-El-Khalick, 1998)	Students have to form hypothesis and perform experiments to inquire about the inner workings of mysterious devices and develop models that account for their observations.	The different forms of scientific knowledge
Tricky tracks (Lederman & Abd-El-Khalick, 1998)	Students observe a set of animal tracks from a zoomed-in perspective. The vantage point widens to reveal more data during the activity. They develop interpretive stories to account for the patterns they observe.	Scientific knowledge varies in certainty
The hole picture (Lederman & Abd-El-Khalick, 1998)	Students have to figure out the color and shape of cut outs in a manila folder by observing them through small holes in the folder.	Diversity of scientific methods, Scientific knowledge varies in certainty

Table 3-4. Continued

The check lab (Loundagin, 1999)	Students are draw randomly from a set of checks and create a story to account for the data they encounter.	Diversity of scientific methods, Scientific knowledge varies in certainty
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Table 3-5. Data collection and analysis phases during and immediately following the research apprenticeship experience

Time frame	Data collection/analysis	Participants
Week 1	ISS Pre-survey	All participants from all seminars (n=30)
Week 2	Identification of case study participants based on ISS Pre-survey ratings	2 participants from each seminar. Students with similar Pre-rating and with room for growth (n=6)
Week 2	Follow-up Pre-survey interviews	Case study participants (n=6)
Weeks 2-7	Observations/field notes and interviews	Case study participants (n=6)
Week 6	ISS Post-survey	All participants from all seminars (n=30)
Week 7	Follow-up Post-survey interviews	Case study participants (n=6)
Post-apprenticeship	Mentor interviews	Mentors (PI and Graduate students) of final case study participants (n=12)

ISS, Ideas about Science Survey

Table 3-6. Examples of initial, focused and theoretical codes

Examples of Codes				
Initial Codes				
Acceptance of ideas	Feelings about apprentice	Mentor confidence in apprentice	Purpose of project	Social interactions in lab
Analyzing data	Implications of results	Modification of protocols	Recording in laboratory notebook	Statistics
Apprentice contributions	Importance of project	Novelty of project	Role of evidence	Support to pursue science
Apprentice given choice	Independence	Ownership of project	Satisfaction	Unexpected results
Belonging	Laboratory group	Participating in research	Scientific method	Using computers
Calculating	meetings	Positioning in the lab	experienced	Value of apprentice
Collaboration	Learning from past experiments	Pride	Set backs to research project	Value of the project
Confidence	Trial and error			
Encountering challenges	Limited progress			
Epistemic involvement				
Errors				
Focused Codes Grouped by Theme (Theoretical Codes)				
Authentic Action	Being Treated Authentically	Feelings of Authenticity		
Analyzing data	Accepting ideas of apprentice	Belonging described		
Calculating	Confidence in apprentice	Comfort felt		
Collaboration	Encouraging the apprentice	Excitement of apprentice		
Encountering Challenges	Mentor availability	Importance of project explained		
Epistemic involvement	Mentor positioning of the apprentice in the lab	Interest in project		
Laboratory group meetings experienced	Mentor patience	Ownership of project		
Learning from past experiments	Positive feelings about apprentice	Positioning in the lab		
Participating in research	Recognizing apprentice contributions	Pride		
Statistical analysis	Recognizing the value of the apprentice	Purpose of project understood		
Trial and error	Social interactions in lab	Satisfaction described		
Unexpected results		Scientist identity developed		
Using computers		Value of the experience described		
Working on novel project				

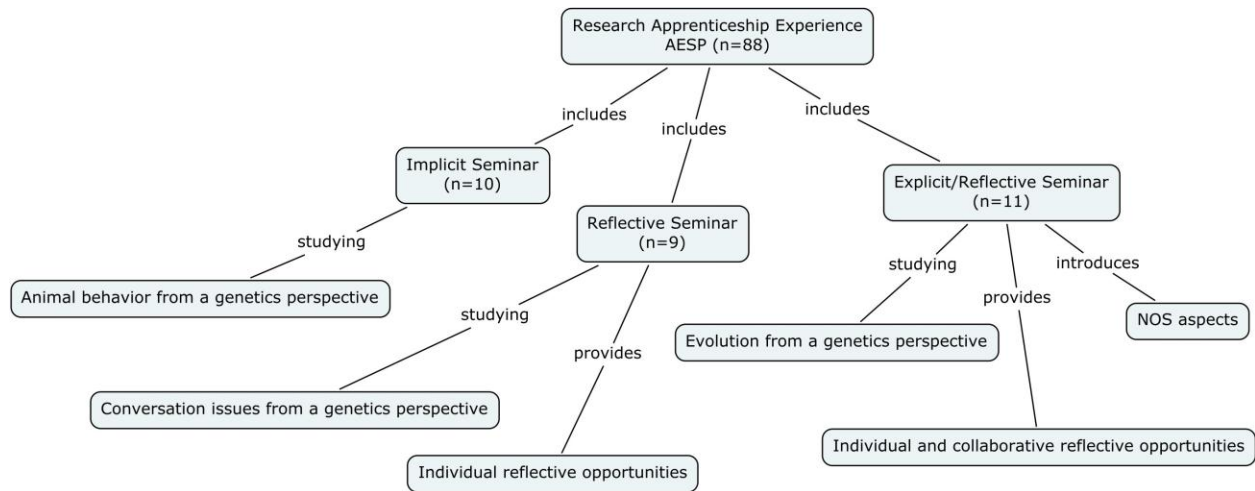


Figure 3-1. NOS teaching and learning interventions in the context of a research apprenticeship experience.

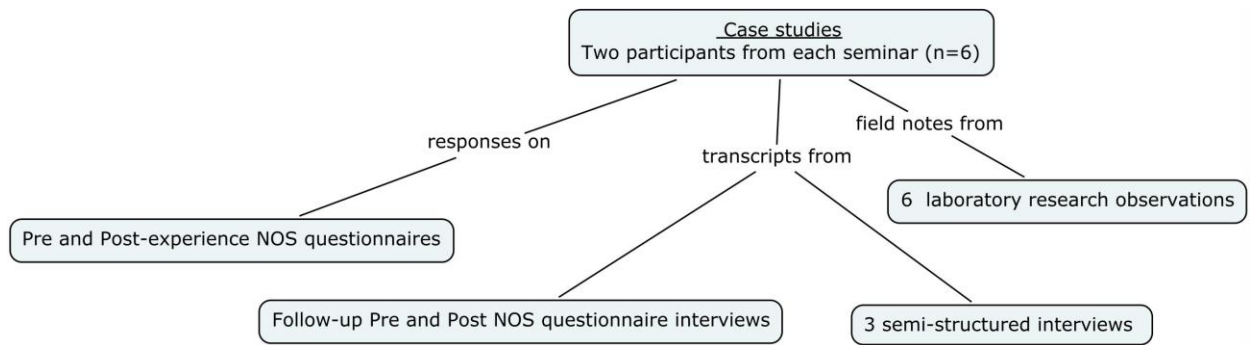


Figure 3-2. Data sources from which case studies are built

CHAPTER 4 CHANGES IN PARTICIPANT NOS IDEAS

Introduction

Prior to an investigation of the influencing factors on changes in NOS ideas, it was important to have a robust picture of just what were the NOS ideas of the participants of this study both at the beginning and at the end of the program and the ways in which these understandings had changed. Of additional import was an understanding of how changes in NOS ideas varied for participants experiencing the three different interventions implemented in this study. An overview of the findings related to participant changes in NOS ideas is presented in this chapter. These results are both qualitative and quantitative in nature and presented in a series of tables containing participant written responses to the Ideas about Science Survey (ISS) and subsequent categorical data analysis of those responses. A comparison of the written survey responses with corresponding interviews regarding those responses for the six case study participants closes the chapter.

NOS Ideas Revealed through the ISS

A majority of the data analyzed during the exploration of participant NOS ideas were written responses to the ISS (Appendix B) given both at the beginning and again at the end of the Authentic Experiences in Science Program (AESP). Two independent raters analyzed the responses to these surveys by using a typological approach (Hatch, 2002) whereby a-priori categories guided the analysis process. That is to say that the surveys were examined holistically for instances of naïve, mixed, informed and unknown responses regarding eight different NOS aspects (Lederman et al., 2002; Sandoval, 2005). A coding rubric was created to help the raters through this analysis

process (Appendix F). This rubric contains descriptions of naïve, mixed and informed responses for each targeted NOS aspect as well as which survey questions relate to which aspect (Lederman et al. 2002). Additionally, in order to keep levels of inference low, ratings of unknown were given when the researchers decided that not enough information was provided by the participant to adequately characterize his/her response. This unknown category was one that was not an original part of the research plan but emerged from the data. An agreement of 100% on all of the ratings for each participant was reached through a process of consensus building discussions between the two raters. This process was thoroughly described in Chapter 3.

Before entering into a discussion of the pre-experience NOS ideas, the post-experience NOS ideas and the changes in NOS ideas for the participants in this study, representative written survey responses are presented for each NOS aspect. Table 4-1 contains these responses. Each example is identified as being either from the pre-survey or the post-survey. An individual number identifies each participant. Since survey responses from the six case study participants will be discussed in Chapter 5, examples in Table 4-1 are all from non-case study participants. Both a naïve example and an informed example are provided for each NOS aspect. Since most of the mixed responses contained elements of both a naïve and an informed understanding, the decision was made not to include representative examples of mixed responses in the table.

Pre-experience NOS Ideas

All of the pre-survey response ratings for all of the investigated NOS aspects are provided on Table 4-2 for each participant in the study. An individual number identifies participants and an asterisk further identifies case study participants. Participants are

further divided into three intervention groups based on the seminar in which they were enrolled. A quick examination of this table reveals that at the beginning of the experience, participant understandings of the distinction between theories and laws as different forms of scientific knowledge, and the myth of the scientific method were the least informed with 73% and 57% of all of the responses rated naïve respectively. Participant understandings of the empirical nature of scientific knowledge and the tentative nature of scientific knowledge were the most informed with only 10% and 7% of all of the responses rate naïve respectively. Prior views regarding the creativity involved in conducting scientific research, the subjective nature of scientific knowledge, the social-embedded nature of scientific knowledge and that scientific knowledge is constructed rather than discovered were more varied in that a balanced mixture of naïve, informed and mixed views permeated all of the ratings for all of the participants regardless of the seminar in which they were enrolled. This uniformity between prior NOS views between different intervention groups will be addressed in a separate discussion.

Post-experience NOS Ideas

All of the post-survey response ratings for all of the investigated NOS aspects are provided on Table 4-3 for each participant in the study. At the end of the experience, participant understandings of the distinction between theory and law were still the most naïve, but now only 57% of the responses were naïve compared with the 73% of responses being rated naïve for this aspect at the beginning of the experience. At the end of the experience only 30% of the responses related to the myth of the scientific method were rated naïve. At the beginning of the experience, 57% of the same responses were rated naïve. It is clear from an examination of the pre and post ratings

of these two NOS aspects that participant understandings were being positively impacted to a certain degree over the course of the program. What remains uncertain is an understanding of whether or not certain intervention seminars were more effective at influencing this change than were others.

Changes in NOS Ideas

Table 4-4 provides a visualization of the changes in NOS ideas by aspect and by participant. On the table, not only are positive changes represented, but negative changes in NOS ideas are represented as well. Participants in the explicit/reflective seminar exhibited more positive changes in NOS understandings than did participants in either of the other two seminars. Positive changes in understandings of a single NOS aspect occurred 32 times for the participants of this seminar. In comparison, there were 11 instances of positive changes in NOS understandings for the members of the reflective seminar and nine instances of positive changes in NOS understandings for the members of the implicit seminar. Additionally, the understandings of NOS ideas decreased in their level of sophistication only three times for the participants of the explicit/reflective seminar. Such decreases in understandings of NOS ideas occurred 10 times among the members of the reflective seminar, and 15 times for the members of the implicit seminar. It is apparent from these results that differences in changes of NOS understandings were clearly present between the three different intervention groups. It is also evident that understandings of the differences between scientific theories and laws as forms of scientific knowledge, the social-cultural embeddedness of science and the myth of the scientific method were the NOS aspects with the greatest instances of positive change among the members of the explicit/reflective seminar.

However, questions still remain about these results. Are the changes in NOS understandings significantly different from each other for the three different intervention groups? Do certain NOS aspects exhibit more significant changes for certain intervention groups than do other NOS aspects? This last question was not one that was included in the research questions that guided the design of this study. Rather, the question emerged during the analysis of the written survey responses at the end of the program. It was quite evident to the researchers that participant understandings of certain NOS aspects were exhibiting more changes than were others. Categorical data analysis techniques were applied in order to explore the significance of the changes in NOS understandings exhibited by the members of the three different seminars and to examine whether or not some NOS aspects were being impacted in more significant ways than were others. In the sections that follow, results of statistical analyses of the qualitative ratings attributed to participant responses to the written science survey are discussed.

Kruskal-Wallis/Wilcoxon Rank Sum Analysis Results

A Kruskal-Wallis/Wilcoxon rank sum test was used to determine if there were any significant differences ($p < 0.05$) between the NOS ideas at the beginning of the experience, the NOS ideas at the end of the experience and the changes in NOS ideas among the participants of the three different intervention seminars. A 95% confidence interval was used when discussing significance due to the small sample sizes in this study. The results of this analysis can be seen in Table 4-5. For the purposes of running such an analysis, all unknown NOS ratings were removed for each participant. Ratings were then assigned a numerical score. A score of one was given to any naïve ratings, a score of two was given to any mixture ratings and a score of three was given to any

informed ratings. In this way, all participants could be assigned a composite score for both their pre and their post surveys. These scores could then be compared in a variety of ways. When all of the pre-survey responses were compared, there was no significant difference in the scores between the average pre-survey score for the three different intervention groups. Such a result indicates that the participants were entering the authentic research program with similar prior conceptions about NOS. However, a comparison of the post-survey response ratings and the changes in survey response ratings pre to post-experience revealed significant differences between the three intervention groups. The differences between pre-survey and post-survey responses for each seminar were then compared to those differences for both of the other two intervention seminars. It was revealed that as a whole this difference for the explicit/reflective seminar was significantly different from both the reflective and the implicit seminar difference scores. The pre to post difference scores for implicit and the reflective seminars were not significantly different from each other. This result indicates that the change in NOS ideas exhibited by the members of the explicit/reflective group was significantly different from the change in NOS ideas exhibited by the members of both the implicit and the reflective seminars. Additionally the change in NOS ideas exhibited by the members of the implicit seminar was not significantly different from the change in NOS ideas exhibited by the members of the reflective seminar.

McNemar Analysis Results

The McNemar significance of change test was used to determine if the desired changes in participant understandings of the targeted NOS aspects were significant ($p < 0.05$) for the members of the three different intervention groups. The results of this test are provided in Table 4-6. In the table, some statistics are not available. Absent

statistics occurred when the NOS ratings were identical before and after the experience. Additionally the word “none” appears in a few places. This indicates that the statistic was unable to be calculated due to small cell sizes. The only intervention group that exhibited significant changes in NOS understandings was the explicit/reflective seminar, and these changes were only regarding understandings of the distinctions between theories and laws and the myth of the scientific method. While not statistically significant, it should be noted that understandings of the social-embedded nature of scientific knowledge exhibited a trend ($p=0.0588$) toward more sophisticated understandings for the members of the explicit/reflective seminar.

Limitations of Written Survey Results

Before moving on, it is worth mentioning some of the limitations to the use of a statistical analysis of the open-ended ISS as the only means of measuring change in NOS ideas for the participants of this study.

Instances of Reflective and Implicit change

An overreliance on the results of the categorical analysis of the written survey data could result in an interpretation that NOS ideas were not impacted for the members of either the reflective or the implicit seminars. However, this was not the case (Table 4-4). While the only statistically significant whole group changes in NOS ideas occurred for the explicit/reflective group, there were instances of individual positive and negative changes in NOS understandings within both the reflective and the implicit groups. Fortuitously some of these participants happened to be case study participants. For them, a number of other data sources including interviews and observations gave insight into possible influencing factors related to the positive changes in their NOS ideas. Unfortunately, these additional data sources were only available for case study

participants who were selected early in the data collection phase of the research study. As a result, no information is available to account for factors that may have negatively influenced the NOS ideas of the participants who exhibited such negative change as none of them were case study participants.

Mismatch between Written Survey Responses and Survey Interview Data

The six case study participants were interviewed about their written responses following both administrations of the ISS. During these interviews, participants were provided with the original copy of their survey containing their written responses and asked to elaborate on what they meant by what they wrote. Additional questions were also asked and are found in the interview protocol in Appendix B. These interviews were transcribed and then coded according to relevant NOS aspects. Interviews were then rated in the same way as were the written responses. Table 4-7 shows the comparison between the written survey data and the interview data for the first administration of the ideas about science survey for the six case study participants. The consistency between the ratings given to these two data sources was 79.2%. Many unknown ratings given to written science survey responses were clarified during the interview process. Such a change in rating from unknown to known was not described as being inconsistent. Inconsistencies in this table are marked with an asterisk. Table 4-8 displays the same information regarding the consistency between the written responses and the interview responses regarding the second administration of the ideas about science survey. Here, the consistency was 81.3%. Finally, Table 4-9 shows the comparison between the pre to post change in NOS ideas revealed through the written survey responses and the science survey interview data. The consistency between these changes was 79.2%. This table differs slightly from Table 4-4 in that it displays unknown changes in NOS

ideas. For example, if a student's prior-experience view regarding a NOS aspect was rated as being unknown, but their post-experience view regarding that same aspect was rated as being informed, their change in understanding of this NOS aspect would have been unknown. When case study participants were interviewed, many of these unknown changes were clarified.

The mismatch between ratings given to written survey responses and those given to survey interview responses indicates that what participants wrote did not always fully explain their NOS perspectives. A participant may have written something that was rather naïve, but as they were provided with an opportunity to discuss what they actually meant, at times they would elaborate and supplement their written response with more informed NOS ideas. Thus a naïve written response in this instance would have been paired with a mixed rating for the survey interview response. For this reason, interview data were prioritized over written survey data when discussing the NOS ideas of the case study participants.

Conclusion

In summary, the use of written survey data revealed significant overall positive group changes in understandings of the distinction between theory and law and of the myth of the scientific method for the members of the explicit/reflective seminar. Understandings of the social-cultural embeddedness of scientific knowledge for this group as a whole trended towards positive changes. However, there were individual exceptions where members of both the reflective and the implicit seminars exhibited positive and negative changes in certain NOS aspects. These findings reveal the power of implicit messages to impact NOS understandings both for the good and for the bad. With the six case study participants, survey interviews revealed some inconsistencies

between the ratings of their written responses and the ratings applied to their interview transcripts. Such findings speak to the limitations of the use of written open-ended questionnaires as the sole means of assessing NOS understandings.

Table 4-1. Examples of written science survey responses and ratings

NOS Aspect	Naïve example	Informed example
Empirical	When asked why scientists disagree about dinosaur extinction: "Because they don't have scientific proof or remains today to prove it." (Participant 6, Pre-Survey)	When asked why scientists disagree about dinosaur extinction: "The way they interpret the information differs." (Participant 22, Post-Survey)
Theory/Law	"Scientific theory is something established as a possibility, but not fact. Scientific law is something established as fact." (Participant 28, Post-Survey)	"A scientific law is something that governs our existence and cannot (okay, should not) be broken; whereas a scientific theory is a well-tested and proven explanation of how a scientific phenomenon occurs." (Participant 20, Pre-Survey)
Creative	"When in the process of an experiment you should just mark what you see, no creativity or imagination." (Participant 9, Pre-Survey)	"Making observations and writing a discussion of the results are probably the most common parts of a scientific investigation to use creativity." (Participant 2, Post-Survey)
Subjective	"Science is objective. It draws from data that is collected under controlled conditions. This is unlike subjective disciplines, in which much can be left for interpretation." (Participant 5, Pre-Survey)	"The differing cultures, backgrounds, and beliefs of scientists cause them to leap to differing conclusions about even the same situation." (Participant 1, Post-Survey)
Social-embeddedness	"Science is universal. That is one of the bases of science, symmetry." (Participant 17, Post-Survey)	"Science is usually around in time of need. The needs of certain cultures are different from others. So yes, science can reflect social and cultural values." (Participant 13, Pre-Survey)
Tentative	"I believe what we know now will not change later on unless the universe changes along with science." (Participant 14, Pre-Survey)	When asked if scientific knowledge may change in the future: "Yes, nothing is permanent, especially science. For example, at one point we believed in a geocentric universe when in fact the earth actually revolves around the sun." (Participant 10, Post-Survey)
Myth of the Scientific Method	When asked if all scientists used the scientific method: "Yes, to be completely sure of a set pattern to follow." (Participant 29, Post-Survey)	"The method according to high school is state problem, research, hypothesis, experiment, collect data, analyze and form conclusion. I believe this is wrong. There is no one way to conduct the scientific method." (Participant 25, Pre-Survey)
Constructed	"I think scientific knowledge is discovered. The answers to the questions are found through experimentation and research not made out of nowhere." (Participant 12, Post-Survey)	"Scientific knowledge is constructed based upon a foundation set by predecessors." (Participant 17, Pre-Survey)

Table 4-2. Participant pre NOS understandings by aspect as revealed on written science surveys

Sem.	Part.	Emp.	T/L	Cre.	Sub.	Soc.	Tent.	Meth.	Const.
E/R	1	I	I	I	I	M	I	N	M
E/R	2	M	N	I	U	I	I	M	M
E/R	3*	M	N	I	M	I	M	I	N
E/R	4*	M	N	N	N	N	I	N	N
E/R	5	I	N	M	N	N	I	N	N
E/R	6	N	N	N	N	N	N	N	I
E/R	7	I	N	N	M	N	I	N	M
E/R	8	M	N	I	I	M	M	I	N
E/R	9	M	N	N	U	U	M	N	N
E/R	10	I	N	I	I	M	I	I	M
E/R	11	I	I	N	N	N	M	N	N
R	12	N	N	N	N	N	I	N	N
R	13	M	N	I	U	I	U	M	M
R	14	M	N	N	U	N	N	M	N
R	15*	I	N	N	U	N	M	M	M
R	16	I	N	I	I	N	M	N	N
R	17	I	N	N	N	N	I	N	I
R	18*	I	U	I	I	M	I	N	N
R	19	I	N	N	I	N	I	M	N
R	20	I	I	I	U	M	I	I	I
Im	21	I	U	I	M	N	I	M	M
Im	22	M	N	I	I	M	I	N	I
Im	23	I	I	I	M	I	I	N	I
Im	24*	M	N	I	U	I	U	I	N
Im	25	M	N	N	M	M	I	I	M
Im	26	M	U	I	I	I	I	I	M
Im	27*	M	U	N	I	N	I	N	I
Im	28	N	N	N	U	N	I	N	N
Im	29	I	N	I	M	I	I	N	N
Im	30	I	N	U	I	I	I	N	U

Seminar (Sem.): Explicit/Reflective (E/R), Reflective (R), Implicit (Im);

Participant (Part.), Case study participant (*);

NOS Aspects: Empirical (Emp.), Theory/Law (T/L), Creative (Cre.), Subjective (Sub.),
Social-Embedded (Soc.), Tentative (Tent.), Myth of the Scientific Method (Meth.),
Constructed (Const.);

NOS Ratings: Unknown (U), Naïve (N), Mixture (M), Informed (I)

Table 4-3. Participant post NOS understandings by aspect as revealed on written science surveys

Sem.	Part.	Emp.	T/L	Cre.	Sub.	Soc.	Tent.	Meth.	Const.
E/R	1	I	I	I	I	I	I	I	M
E/R	2	M	M	I	M	N	I	M	N
E/R	3*	I	N	I	I	I	I	I	N
E/R	4*	I	U	I	M	I	I	I	N
E/R	5	I	I	M	M	I	I	I	N
E/R	6	N	U	I	U	I	M	M	N
E/R	7	I	I	M	U	N	I	I	M
E/R	8	M	I	I	I	I	I	I	M
E/R	9	M	I	N	N	N	M	M	N
E/R	10	I	N	I	I	M	I	I	M
E/R	11	I	I	N	I	I	M	M	M
R	12	M	N	I	U	N	I	N	N
R	13	I	N	I	U	U	M	N	M
R	14	M	N	M	I	U	I	I	N
R	15*	I	N	I	I	N	I	M	M
R	16	I	N	N	I	N	I	N	U
R	17	M	N	N	N	N	M	N	M
R	18*	I	N	I	I	U	I	I	N
R	19	M	N	N	I	M	I	N	M
R	20	I	U	I	M	N	I	M	M
Im	21	I	U	I	I	I	I	N	N
Im	22	I	N	I	I	N	I	M	M
Im	23	I	N	I	M	I	I	N	N
Im	24*	M	N	I	U	U	I	I	N
Im	25	M	N	I	N	N	I	I	M
Im	26	M	U	I	I	M	I	I	N
Im	27*	M	U	N	I	N	M	N	M
Im	28	M	N	I	I	N	I	I	N
Im	29	I	N	I	U	U	M	N	N
Im	30	M	N	I	I	M	I	M	M

Seminar (Sem.): Explicit/Reflective (E/R), Reflective (R), Implicit (I);

Participant (Part.), Case study participant (*);

NOS Aspects: Empirical (Emp.), Theory/Law (T/L), Creative (Cre.), Subjective (Sub.),
Social-Embedded (Soc.), Tentative (Tent.), Myth of the Scientific Method (Meth.),
Constructed (Const.);

NOS Ratings: Unknown (U), Naïve (N), Mixture (M), Informed (I)

Table 4-4. Participant known changes in NOS understandings by aspect as revealed on written science surveys

Sem.	Part.	Emp.	T/L	Cre.	Sub.	Soc.	Tent.	Meth.	Const.
E/R	1					+		+	
E/R	2		+			-			-
E/R	3*	+			+		+		
E/R	4*	+		+	+	+		+	
E/R	5		+		+	+		+	
E/R	6			+		+	+	+	-
E/R	7		+	+				+	
E/R	8		+			+	+		+
E/R	9		+					+	
E/R	10								
E/R	11				+	+		+	+
R	12	+		+					
R	13	+						-	
R	14						+	+	
R	15*			+			+		
R	16			-			+		
R	17	-					-		-
R	18*							+	
R	19	-				+		-	+
R	20					-		-	-
Im	21				+	+		-	-
Im	22	+				-		+	-
Im	23		-						-
Im	24*								
Im	25			+	-	-			
Im	26					-			-
Im	27*						-		-
Im	28	+		+				+	
Im	29						-		
Im	30	-				-		+	

Seminar (Sem.): Explicit/Reflective (E/R), Reflective (R), Implicit (Im);
Participant (Part.), Case study participant (*);
NOS Aspects: Empirical (Emp.), Theory/Law (T/L), Creative (Cre.), Subjective (Sub.),
Social-Embedded (Soc.), Tentative (Tent.), Myth of the Scientific Method (Meth.),
Constructed (Const.);
Change in NOS Understandings: Positive change (+), Negative change (-)

Table 4-5. Kruskal-Wallis/Wilcoxon Rank Sum analysis of science survey data

Description of Test	Chi-Square	d.f.	p
Pre-Survey. Comparison of All Seminars	1.6792	2	0.4319
Post-Survey. Comparison of All Seminars	7.7266	2	0.0210*
Pre-Survey to Post-Survey Differences. Comparison of All Seminars	6.8424	2	0.0327*
Pre-Survey to Post-Survey Differences. Comparison of Explicit/Reflective and Reflective Seminars	4.2558	1	0.0391*
Pre-Survey to Post-Survey Differences. Comparison of Explicit/Reflective and Implicit Seminars	5.4891	1	0.0191*
Pre-Survey to Post-Survey Differences. Comparison of Reflective and Implicit Seminars	0.1370	1	0.7112
Degrees of Freedom (d.f.). Significant p value (*)			

Table 4-6. McNemar analysis of science survey data.

Aspect	Seminar	Statistic (S)	d.f.	p
Empirical	Explicit/Reflective	2.0000	1	0.1573
	Reflective	0.3333	1	0.5637
	Implicit	0.0000	1	1.0000
Theory/Law	Explicit/Reflective	4.0000	1	0.0455*
	Reflective	N/A	N/A	N/A
	Implicit	N/A	N/A	N/A
Creative	Explicit/Reflective	2.0000	1	0.1573
	Reflective	0.3333	1	0.5637
	Implicit	2.0000	1	0.1573
Subjective	Explicit/Reflective	2.0000	1	0.1573
	Reflective	None	1	None
	Implicit	1.0000	1	0.3173
Social-Embed	Explicit/Reflective	3.5714	1	0.0588 (trend)
	Reflective	N/A	N/A	N/A
	Implicit	0.3333	1	0.5637
Tentative	Explicit/Reflective	2.0000	1	0.1573
	Reflective	1.0000	1	0.3173
	Implicit	N/A	N/A	N/A
Myth of Method	Explicit/Reflective	4.0000	1	0.0455*
	Reflective	0.3333	1	0.5637
	Implicit	1.0000	1	0.3173

Degrees of Freedom (d.f.). Significant p value (*). Statistic Not Available (N/A).

Table 4-7. Case study pre NOS understandings. Comparison of written surveys with survey interviews.

Sem.	Part.	Emp.	T/L	Cre.	Sub.	Soc.	Tent.	Meth.	Const.
Written Survey Response Ratings									
E/R	3 Jennifer	M	N	I	M	I	M	I	N
E/R	4 Jane	M	N	N	N	N	I	N	N
R	15 Isabel	I	N	N	U	N	M	M	M
R	18 Joseph	I	U	I	I	M	I	N	N
Im	24 Tom	M	N	I	U	I	U	I	N
Im	27 John	M	U	N	I	N	I	N	I
Survey Interview Response Ratings									
E/R	3 Jennifer	M	N	I	M	I	M	*M	N
E/R	4 Jane	U	N	N	N	*M	*M	N	N
R	15 Isabel	U	N	N	M	*M	M	*N	M
R	18 Joseph	I	N	*N	*M	M	I	N	N
Im	24 Tom	M	N	I	I	*M	I	I	N
Im	27 John	M	N	N	U	N	*M	N	*M

Seminar (Sem.): Explicit/Reflective (E/R), Reflective (R), Implicit (Im);

Participant (Part.);

NOS Aspects: Empirical (Emp.), Theory/Law (T/L), Creative (Cre.), Subjective (Sub.),
Social-Embedded (Soc.), Tentative (Tent.), Myth of the Scientific Method (Meth.),
Constructed (Const.);

NOS Ratings: Unknown (U), Naïve (N), Mixture (M), Informed (I);

Interview Rating Inconsistent with Rating of Written Survey Response (*)

Table 4-8. Case study post NOS understandings. Comparison of written surveys with survey interviews.

Sem.	Part.	Emp.	T/L	Cre.	Sub.	Soc.	Tent.	Meth.	Const.
Written Survey Response Ratings									
E/R	3 Jennifer	I	N	I	I	I	I	I	N
E/R	4 Jane	I	U	I	M	I	I	I	N
R	15 Isabel	I	N	I	I	N	I	M	M
R	18 Joseph	I	N	I	I	U	I	I	N
Im	24 Tom	M	N	I	U	U	I	I	N
Im	27 John	M	U	N	I	N	M	N	M
Survey Interview Response Ratings									
E/R	3 Jennifer	I	N	I	I	I	*M	I	N
E/R	4 Jane	I	I	I	M	I	I	*M	N
R	15 Isabel	I	N	I	I	*M	I	*N	M
R	18 Joseph	I	N	I	I	M	I	I	N
Im	24 Tom	*I	N	I	I	M	I	I	N
Im	27 John	*I	N	*I	I	*M	*I	N	U

Seminar (Sem.): Explicit/Reflective (E/R), Reflective (R), Implicit (Im);

Participant (Part.);

NOS Aspects: Empirical (Emp.), Theory/Law (T/L), Creative (Cre.), Subjective (Sub.), Social-Embedded (Soc.), Tentative (Tent.), Myth of the Scientific Method (Meth.), Constructed (Const.);

NOS Ratings: Unknown (U), Naïve (N), Mixture (M), Informed (I);

Interview Rating Inconsistent with Rating of Written Survey Response (*)

Table 4-9. Case study changes in NOS understandings. Comparison of written surveys with survey interviews.

Sem.	Part.	Emp.	T/L	Cre.	Sub.	Soc.	Tent.	Meth.	Const.
Written Survey Response Ratings									
E/R	3 Jennifer	+			+		+		
E/R	4 Jane	+	U	+	+	+		+	
R	15 Isabel			+	U		+		
R	18 Joseph		U			U		+	
Im	24 Tom				U	U	U		
Im	27 John		U				-		-
Survey Interview Response Ratings									
E/R	3 Jennifer	+			+		*	*+	
E/R	4 Jane	U	+	+	+	+	*+	+	
R	15 Isabel	U		+	+		+		
R	18 Joseph			*+	*+			+	
Im	24 Tom	*+							
Im	27 John	*+		*+	U	*+	*+		U

Seminar (Sem.): Explicit/Reflective (E/R), Reflective (R), Implicit (Im);

Participant (Part.);

NOS Aspects: Empirical (Emp.), Theory/Law (T/L), Creative (Cre.), Subjective (Sub.), Social-Embedded (Soc.), Tentative (Tent.), Myth of the Scientific Method (Meth.), Constructed (Const.);

Change in NOS Understandings: Unknown Change (U), Positive Change (+), Negative Change (-);

Interview Rating Change Inconsistent with Rating of Written Survey Response Change (*)

CHAPTER 5 FACTORS INFLUENCING CHANGES IN PARTICIPANT NOS IDEAS

Introduction

An identification and discussion of the influencing factors that were tied to changes in NOS ideas for the six case study participants is presented in this chapter. The chapter is wholly qualitative in nature and is organized into six separate stories, one for each case study participant. Representative quotes and incidents from interview and observational data permeate each case study story. Within these stories, a system of abbreviations has been used to identify the data source that each specific piece of evidence came from. This system is described in Table 5-1. Also included in this chapter is the constructed theory that accounts for the sources that led to NOS changes among participants.

Theoretical Codes

Prior to the individual case study reports, it is important to give a brief description of each theoretical code that makes up a portion of each participant's story. These three theoretical codes are authentic action, being treated authentically and feelings of authenticity. They emerged from an application of constructivist grounded theory as an analysis technique (Charmaz, 2006). Through a process of iterative coding strategies followed by a constant comparative analysis (Glaser & Strauss, 1967) within individual cases and among the entire group of case study participants the codes were truly grounded in the data. Table 3-6 contains sample focused codes organized under each of these theoretical code headings. These constructs are intricately related to one another as will be seen throughout the case study stories and discussed when describing the constructed theory at the end of this chapter. For example, the more a

participant was treated authentically within their laboratory placement, the more the participant was allowed to engage in authentic action. As a participant became self-aware of the ways in which he or she was treated authentically and participating in authentic scientific practices, he or she in turn developed feelings of authenticity as he or she built an identity of himself or herself as a scientist. Implicit messages related to specific NOS ideas carried through authentic action were more influential when the student had a positive scientist self-identity. Each of the three theoretical codes will now be briefly described.

Authentic Action

Authentic action in the context of this study is representative of any activity on the part of the case study participant that could be thought of as being a part of the professional practices of working scientists. Observations of laboratory practices combined with corroborating information from participant and mentor interviews were used to develop an understanding of the authentic action the participant was engaged in during the course of the Authentic Experiences in Science Program (AESP). Examples of authentic action included but were not limited to the development of a research question, the design of methods to investigate the question, the revision of those methods, the collection of empirical data, the analysis of data, the interpretation of results, the levels of collaboration experienced and the reporting of research findings.

Being Treated Authentically

Whether or not the program participant was treated in an authentic way during the research apprenticeship appeared to be related to the quality of mentorship received. When a mentor valued the contributions that a participant made when working in his or her lab, listened to and respected the ideas of the participant and recognized the

legitimate role the participant played in the laboratory, the participant was being treated authentically.

Feelings of Authenticity

Feelings of authenticity or a lack thereof on the part of the program participants were a direct result of the authentic action they experienced and the ways in which they were treated authentically. This theoretical code speaks to the identity that the participant developed over the course of his or her experience in the laboratory. Feelings of comfort, belonging, adequacy and inclusion were classified as being authentic. When the participant self-identified these feelings, they also accompanied the development of a scientist identity. Feelings of authenticity impacted the ways in which participants perceived the levels of authenticity of the action in which they were taking part.

Case Study Reports

What follows is a series of stories of the individual case study participants of this study (Table 3-2). Each story begins with a description of the background of the student, the laboratory in which they were placed and their research project. Next, the changes in NOS ideas for each case study participant as revealed through both written survey data and corresponding survey interview data are summarized. Following this, self-reported changes in NOS ideas and influencing factors related to these changes as revealed through participant and mentor interview data are described. Each story concludes with a discussion organized around the major themes (theoretical codes) that were used to group the focused codes that emerged through an application of constructivist grounded theory.

The six case study reports are presented in order from the participant that experienced the lowest levels of authenticity in their respective laboratory placement to the participant that experienced the highest levels of authenticity in terms of action, feelings and treatment. Figure 5-1 is a continuum of authenticity for the six case study participants. Each participant is placed along the continuum according to the levels of authenticity he or she experienced. On this figure, ratings of low, medium and high are provided for each participant for each theoretical code. Following all six stories, the emergent and constructed theory of the influencing factors related to changes in NOS ideas for the six case study participants is presented.

Jane's Story

Background

Jane had no experience participating in authentic scientific research prior to her involvement in the AESP. She did acknowledge completing a science fair project in fifth grade but dismissed it as not being all that unique of an experience when compared with the AESP. "I'm pretty sure everyone does that [Science Fair]" (I1). Jane's father was a doctor and she described getting some exposure to science as a result. In terms of high school course work preparation, Jane had extensive background in a variety of sciences, particularly in chemistry. Prior to entering her senior year of high school, she had already successfully completed one year of biology, one year of physics and two years of chemistry.

At the beginning of the AESP, Jane wanted to be a doctor and was considering majoring in chemistry as a result of her early experiences in the laboratory. "Well I want to be a doctor, but I really like chemistry so I'm thinking about majoring in something related to that and what I'm doing now is interesting to me, my lab" (I1). She went on to

describe how her laboratory work prompted her to consider majoring specifically in biochemistry.

I didn't take enough bio to really think about it, like seriously. But now doing what I'm doing in the lab has made me think more about doing biochemistry in the future...I feel like if I can do it now, then I'll be able to do it in college.
(I1)

At the end of the experience, Jane still intended to pursue a career in medicine.

Jane enrolled in and was a participant of the explicit/reflective seminar.

Additionally, she was the only AESP participant in the laboratory in which she was placed.

Laboratory description

The laboratory where Jane conducted her research as a part of the AESP was representative of a typical laboratory in the chemistry department at the research university where the research apprenticeship program took place. The shelves and cabinets were full of a variety of chemical substances and solutions. Equipment such as pipettes, an incubator and an autoclave were clearly visible around the laboratory. Half a dozen graduate students worked as a part of the laboratory group. They had decorated their individual laboratory workspaces with personal items such as family pictures. These graduate students appeared to be welcoming of Jane, although they were very quiet and worked rather independently. Apart from Jane's graduate student mentor, Brad, not one of them was observed interacting with Jane during any of the six weekly laboratory observations. The laboratory group itself was conducting research organized around investigations related to nonribosomal protein synthesis in roundworms. Research posters as well as humorous comic strips related to this topic decorated the walls around the room.

Project description

Jane had a hard time explaining her project during interviews. The explanations she gave did not lead the researcher to believe that she truly grasped the intricacies of her research. Based on an examination of her research paper, the purpose of her project was to determine ideal Enzyme-Amino Acid pairs that could be used to artificially synthesize antibiotics. Roundworms were used as the hosts for this synthesis process.

Jane's project was in no way a self-determined project. She was merely serving as a data collector for a project that Brad was working on that was a continuation of the work that the laboratory group as a whole was completing. As will be described in greater detail in the sections below, Jane spent much of her time transferring round worms from one petri dish to another under a microscope in order to keep them alive. Such work was indicative of a laboratory assistant rather than a laboratory researcher in this laboratory context.

Changes in NOS ideas

Jane's responses to the Ideas about Science Survey (ISS) coupled with corresponding interviews about those responses revealed positive changes in her understandings of the empirical nature of scientific knowledge, distinctions between theories and laws in science, the creativity involved in scientific knowledge production, the subjective nature of science, the social-embeddedness of scientific knowledge construction, the tentative nature of scientific knowledge and the myth of the scientific method (Table 4-9). Table 5-2 contains representative excerpts from these data sources for Jane that illustrate her pre-experience views and her post-experience views related to each of the aforementioned NOS aspects.

Self reported changes in NOS ideas and corresponding influencing factors

When asked how her views of NOS may have changed over the course of the AESP, Jane self-identified changes in her understandings of the creative nature of science, the subjectivity of science, the social-embeddedness of science and the myth of the scientific method. These self-reported changes are evidenced by the following interview quotes.

The main difference [in my NOS understandings] had to do with like how a person is involved in, like how their personalities and how their creativities are involved in their science...I thought science was totally objective, but now I see how...your cultural and social differences can play a factor in science. (SI2)

I thought unless you do the scientific method you weren't really doing science, but especially since my lab involved like science without the scientific method, I can see how that's not true. (SI2)

The PI of Jane's laboratory, Dr. Stevens, thought that Jane may have encountered some experiences in the laboratory environment that may have influenced her understandings related to the myth of the scientific method.

Well, she probably saw that this schedule is very kind of open. You know you're solving problems and it's sort of up to you to solve them. She might have seen that you run into a lot of obstacles [when conducting scientific research]. (MI1)

Jane identified two influencing factors related to her changes in these NOS ideas. Regarding the changes related to the social embedded nature of scientific knowledge and the subjectivity of science, she believed that the explicit/reflective seminar played the largest impact. This is evidenced by the following quotes.

Because you see [in the seminar] how like even though we're all staring and looking at the same thing [duck/rabbit picture], we all saw different things. Like the pictures at the beginning of the seminar, we all thought of things differently. (SI2)

I think a lot of the activities [influenced my perceptions]. Like the one with the strings and the tube, just seeing how everyone had different ideas of what it could be, like there are just so many ways you could think of things or interpret things. (SI2)

Jane also thought that the journal writings had an impact on her understandings of science.

They [the journal prompts] just made me think, like as I was writing...I would maybe write something down and think oh it could also be this other thing, so it made me see like two different sides of what I was saying and the two sides of the argument. (SI2)

As far as the changes related to her understandings of the creative nature of science and the myth of the scientific method, Jane recognized that the laboratory itself played the biggest factor in influencing her ideas.

Definitely my lab [was the most influencing factor], because my lab didn't have a hypothesis and it involved changing the method instead of using a specific method to come to the conclusion. So just seeing like how we worked with that [influenced my perceptions]. (SI2)

Authentic action

While one could argue that the project that Jane was involved in was an authentic project in that it was itself valuable within a scientific discipline, she personally did not have much opportunity to participate in the full range of authentic action that accompanied it. In the first place, Jane did not get to participate in the design and development of her project. She was able to witness modifications to the methods employed in her research, but was not observed nor did she report making any personal decisions regarding those modifications. Although she did collect data, she did not do so independently at any point in her project. Brad, her graduate student mentor said, "She hasn't singlehandedly collected any data... So it doesn't look like [she contributed to] any significant progress or significant research in my work. She was doing parts that

I explained to her; led her in some process” (MI2). Jane herself recognized the limited contributions that she was making epistemically to her project and attributed this as the reason for a loss of interest in her project over her time in the AESP.

I think I got a little bit less interested as the summer went on because there wasn't as much for me to do. Like especially lately, because my project finished pretty quickly because I just kind of added on to this project. (I3)

Additionally, the data that Jane was collecting at first were not even used by her laboratory group. Jane herself recognized that it took a while for her data to be treated in an authentic way by her laboratory group.

I was transferring worms, which I've been doing for a couple weeks now. At first it was very like...okay it's just a learning process. We're not going to use these. These are going to become contaminated after you do them. But now it's like we're really doing it so be really careful. And like I had to count worms and he [Brad] actually used that in his data. (I2)

Jane then seemed somewhat surprised when it got to the point that her data were actually being used. She believed that early in the program her involvement in the research was for her own benefit rather than for the contributions actually being made to the laboratory group.

Related to the authentic action Jane experienced in her laboratory placement were the levels of collaboration she encountered over the course of the research apprenticeship. Jane was never observed working with anyone other than with her graduate student mentor Brad, and even those observations were limited. Out of the six laboratory observations, Brad was only there three times. The result of this lack of working with other people was a great deal of downtime in Jane's laboratory. She would use this time to work on her presentation, poster and paper that were required for the AESP. Therefore, for Jane, very little of the over thirty hours a week that she was required to spend in her laboratory was used actually collaborating with other working

scientists as authentic work was being conducted. On the contrary, Jane was spending her time in isolation working on required end products of research with which she had had little engagement. Both Jane and Brad seemed frustrated at the lack of collaboration that they had experienced. Jane explained it in the following manner.

A big reason [for our lack of working together] is because he stays really late and involves himself. So then he doesn't end up coming until later. Then also a lot of time he is reading literature. So I'm doing my own work on the computer. (I2)

Brad explained that each Monday his laboratory group had a weekly laboratory group meeting and that Jane attended the first two of these meetings. For the rest of the experience, however, Jane was, according to Brad, uninterested in these meetings and would just show up to the lab and sit by herself doing nothing until the rest of the lab group would arrive. Brad was frustrated with the lack of engagement on the part of Jane. He felt like she missed out on many opportunities for collaboration.

Being treated authentically

Those who were mentoring her over the course of the AESP treated Jane as a visiting high school student. Brad described his role as being a teacher to Jane.

I tried to interact with her as...someone who does teach you what is supposed to be done and what you know is supposed to not be done in the lab...She came in as a high school student to learn. So she hasn't come here with a project. So she was basically following what I teach her to do and what I explained to her to do. It's not like she's here with a project that should be comparable to mine or something like that. (M12)

Brad did say that he tried to "interact with her as a friend" but that Jane did not respond in kind to such interactions (M12). He felt that he had to treat her as a high school student because of how disengaged she was in the laboratory. An example that he gave was regarding how often he would catch her texting on her cell phone. Dr. Stevens backed up this sentiment.

To tell you the truth, she didn't seem very engaged. You know I'm not going to force engagement upon her. You know, she's here to take advantage of the resources and if she doesn't want to take advantage, then yeah. (M11)

Jane's mentors then had the desire to treat Jane in more authentic ways, yet she did not gain their trust and respect to the point that they could actually do so. In their opinion, Jane refused to take advantage of the opportunity that she had been given to participate in authentic scientific research in more genuine ways. As a result, both Brad and Dr. Stevens viewed Jane as a visitor in the laboratory.

At first she was a good student. At first she was a smart student. I felt she could actually contribute and she really takes the time to understand. And I also felt she can be a good researcher if she really stays in the field for a while. (M12)

At the end of the experience, Neither Dr. Stevens or Brad felt the same way about Jane. Rather, they felt that she had never become a working contributor to their laboratory group. When Dr. Stevens was asked to describe Jane's role in the lab she responded, "basically a visitor" (M12). Dr. Stevens said that the reason that Jane was just a visitor was because of the complex nature of their laboratory research.

If you have like something you know that the student could do over and over again, something simple you know, that would, it would help incorporate them into the lab, but our research isn't really like that. You know if Brad had a specific activity that needed to be done everyday, he could train her to do that and she could do it everyday. But that's not how we work around here. (M11)

Feelings of authenticity

Jane personally saw herself falling somewhere in between a working contributor to her laboratory and someone who was just visiting. That being said, at the beginning of the apprenticeship she felt like she was closer to being a working contributor than not. She said, "I feel like I'm a pretty big part of the lab at the moment" (I1). Her position changed somewhat by the time of her second semi-structured interview.

I guess I am a little bit more of a contributor, but I still feel in between [a contributor and a visitor]...I don't feel fully like [a scientist], I feel like what I do isn't used much, but it's just kind of to show me how to do things. (I2)

Jane then did not develop a full scientist identity over the course of her experience in the AESP. She felt like the work that she was doing was artificial to a certain extent in that it was designed for her benefit rather than for the benefit of the professional scientists in her laboratory.

Summary

Of all of the case study participants, Jane was the one who demonstrated the most growth in her understanding of NOS over the course of the AESP. But, compared to the other case study participants, she was in a laboratory where she experienced the least amount of authentic action, the least amount of authentic treatment from her mentors and developed the lowest science self-identity. It is true that Jane did not make a concerted effort to take advantage of the opportunities that were available to her in the lab. Her passive demeanor in the lab was at least partially related to the ways in which her mentors treated her and the activities in which they allowed her to be involved. For these reasons, a majority of the changes in her NOS views were likely related to explicit messages she received in the explicit/reflective seminar rather than to implicit messages she may have received through her participation in the laboratory. This speaks to the power of the explicit/reflective approach in this context.

The explicit/reflective approach was particularly powerful for Jane given that the social nature of scientific work was not experienced by Jane in her laboratory and as a result she may even have received negative implicit messages regarding related NOS aspects. In Jane's case, the explicit activities related to the subjective nature of science and the social-embedded nature of scientific knowledge carried messages that may

have been more powerful for her than were the implicit messages present in her laboratory placement.

Additionally, she self-attributed changes in her understandings of the myth of the scientific method to the actual research that was being conducting in the laboratory in which she had been placed. Perhaps when a student is placed in a laboratory where the research being conducted varies drastically from the traditional scientific method, then even when the student is not authentically involved in conducting the research, he or she still can pick up on the fact that the scientific method is not always followed when scientific research is being conducted. In other words, even positive implicit messages may be present in undesirable laboratory placements in professional scientific contexts for certain NOS aspects.

Isabel's Story

Background

Isabel was a Hispanic student who received a scholarship to attend the AESP. She came from a high school where she was enrolled in a medical magnet program. Isabel intended to pursue a medical related career at the beginning of the program. Her experiences in the program gave her a self-reported confidence to follow through with these plans. "It [my participation in the AESP] has given me more courage going into [college]. I'm not scared of taking chemistry classes that are required for the medical field. I'm not as scared as I used to be" (I3).

Isabel entered the program with extensive content background as a result of her science coursework in high school. She had already completed three years of chemistry, one year of biology and one year of physics prior to entering the AESP.

Isabel recognized that very little laboratory experience had accompanied her school science coursework.

I don't have a lot of lab experience at all really. The work that we did was maybe put some chemicals, like do pH. That's like basically the only lab experience [I have]. I came here [to the AESP] mostly for the lab. (I1)

Additionally, Isabel had completed multiple science fair projects since the third grade. In fact, in the ninth grade she won a school wide first place ribbon for an environmental science project. This same project won fourth place in her county's science fair competition. Isabel described the results of her participation in these science fairs in the following way. "I've been doing science fair projects and so I know the whole hypothesis and all that stuff" (I1). Perhaps Isabel's science fair experience had impacted her views related to the myth of the scientific method prior to the AESP.

Isabel was a member of the reflective seminar and was paired with another AESP participant in her laboratory placement. Isabel herself valued working closely with this other program participant.

Actually it's pretty cool at times. But, ...since the laboratory is pretty small and we're doing the same project, it can get a bit crowded so we have to take turns doing things. But, it is great to have somebody to talk to, like to tell how I feel about this or even ask him questions sometimes. (I2)

The PI of Isabel's laboratory, Dr. Barry, also recognized the value in having two AESP participants working in his lab, but was frustrated that the program itself required the students to turn in two separate papers and two separate presentations even though they were working on the same project. He felt like this unnecessarily minimized the amount of collaboration that the high school students experienced and may have provided them with a misleading picture regarding the amount of collaboration involved in professional scientific research.

When they were working on the same project I felt like it would have been a much better use of time to have them work together on [the paper and presentation]. Because realistically that is how we do it in most disciplines anyway. You know, when I am doing a presentation, or one of my students is doing a presentation there is cross talk where we are going back and forth editing something. You know when we are writing an abstract for a meeting or something there are multiple authors. And different authors are putting in their two cents and then you come out with a composite for the whole group. (MI1)

Laboratory description

Isabel worked in a forest pathology laboratory during the AESP. Kevin, a doctoral student working under Dr. Barry, mentored Isabel. The members of the laboratory group were very inclusive of both Isabel and the other program participant placed with her. Isabel was observed interacting many times with different members of the laboratory group. Multiple members of the laboratory group were observed helping each other out on various research projects including the project that Isabel was working on. One example of this occurred when the program participants were observed as a laboratory technician mentored them as they learned how to perform a DNA extraction technique (O3).

Project description

Isabel investigated the location of a specific fungus (*Raffaelea Lauricola*) within Redbay trees. *Raffaelea Lauricola* is a fungus that is vectored by the redbay ambrosia beetle and is responsible for laural wilt disease, which is fatal to these trees. The project was a part of Kevin's dissertation research. The work involved dissecting redbay trees and preparing petri dishes containing cross-sections from certain parts of the tree. Fungi were then cultured on these samples and DNA exaction was performed in order to identify the fungus present. The purpose of this research was to determine where the

fungus was distributed throughout the tree (e.g. inner sapwood or outer sapwood) in order to help with efforts to combat the disease.

Changes in NOS ideas

Isabel's responses to the ISS coupled with corresponding interviews about those responses revealed positive changes in her understandings of the creativity involved in the production of scientific knowledge, the subjective nature of scientific knowledge and the tentative nature of scientific knowledge (Table 4-9). Table 5-3 contains representative excerpts from these data sources for Isabel that illustrate her pre-experience views and her post-experience views related to each of the aforementioned NOS aspects.

Self reported changes in NOS ideas and corresponding influencing factors

Isabel was asked to identify if any of her NOS ideas had changed over the course of the AESP. She was unable to specifically identify the NOS aspects that had been influenced as revealed through the ISS. That being said, Isabel described that she had not realized before this summer that scientists were so collaborative or that they made mistakes.

I thought they [scientists] only worked by themselves... [But], apparently they have a whole bunch of people they hire. Well, they're not perfect either...they make mistakes, but they still find a way...they were trying to found out why it [the results] had come out with that fungus, or what had happened. (I2)

This new appreciation for the social nature of science might possibly be related to the growth that Isabel experienced in her perspectives regarding the creativity involved in the production of scientific knowledge and the subjectivity of scientific knowledge.

When Isabel's mentors were asked if they thought Isabel understood science differently at the end of the AESP than she had at the beginning, they stated that they

thought that she had come to better appreciate the tentative nature of scientific knowledge and the collaborative processes involved in conducting scientific research. Dr. Barry explained how a literature search might have impacted Isabel's and the other program participant's understandings of the tentativeness of scientific knowledge.

Yeah well, one of the concepts that I had to get across to them was that we don't have all the answers. I think they assumed you know I had them do some literature searches to look for the background information that was needed to do their study. And they looked at it and said, "We couldn't find any answers to these questions" that I gave them. And I think that exercise was really to show them that it [scientific research] is ongoing... That makes it exciting working in biological sciences. That you are working on something new, emerging. There is no established paradigm that can't be challenged... I think sometimes they think of these things as being absolute. That may be because they read textbooks. That's how the teaching of high school students goes. (M11)

Kevin, Isabel's graduate student mentor, thought that Isabel and the other program participant she was working with came to better understand the collaboration involved in science. "That they had a much better understanding of, an appreciation for what the average researcher does. So I think that they were pretty unsure at first, but then got to see all of these people interacting together" (M12). In summary, both Dr. Barry and Kevin were able to recognize some of the changes in NOS that Isabel exhibited on her surveys and that she self-reported through open-ended interviews.

Isabel described both the reflective seminar and the laboratory as being influential in impacting her NOS ideas during her participation in the AESP. As for the reflective seminar, Isabel discussed how the journaling process enabled her to think about science in new ways.

Those questions [in the journals] have never been asked to me before...I answered simply and you'd ask another question, which made me think even more about it and I changed my mind on it. So it definitely made me realize that what I thought was pretty wrong in a way. (I3)

Isabel was describing how when she would respond to a journal prompt, the researcher would give her feedback in the form of questions and ask her to elaborate further. In this way, Isabel was encouraged to reflect deeply on each response. When asked what aspect of the experience was the most influential in impacting her NOS views, Jennifer responded, “It was the laboratory experience. Yeah, the laboratory experience...because it gave me a hands-on experience with it [science]. Like I really didn’t think about it, I actually was part of it” (SI2).

Authentic action

Isabel participated in varying degrees of authentic action as she worked on her research project. Her project was well underway by the time she entered the AESP. As a result, most all of the decisions regarding how to go about answering the research question were made by Kevin prior to the AESP participants even entering the laboratory. Isabel herself recognized that this was the case. “The project has sort of been ongoing, so they already know what to expect or what to try and find out a certain way” (I1). She continued to say that as result she had not really had any opportunities to contribute any original ideas to her project. This lack of being epistemically involved in the development and modification of the research project indicated a limit to the authentic action that Isabel experienced in her laboratory.

However, Isabel was involved in highly authentic levels of data collection and analysis. The work that she was doing was valuable to Kevin as a part of his dissertation and held meaningful real-world applications related to the treatment of tree diseases. Dr. Barry explained how the results of Isabel’s project would not be discarded and that the research group was genuinely excited about the work that Isabel and the

other program participant were completing as part of their experience in the apprenticeship.

I tried to make them feel that their project had a real world implication. That the results that they get would actually be used for something and that it was not just for academic exercise. It was actually something that had a real world application and we were very interested in what the results were going to be. I think that helped them feel like they were part of a team and they were doing work. (MI1)

Isabel and the other program participant in the group worked so well in the laboratory that they learned how to function within it as full working participants of the laboratory. Dr. Barry explained it as follows. “Eventually they knew where all the reagents and equipment was and learned how to use it independently. They didn’t need somebody standing over them constantly and we didn’t” (MI1). Isabel and the other program participant were able to act in such highly authentic ways as they conducted their research that those who were mentoring them were able to give them the freedom to work independently.

Collaboration was also something that was experienced by Isabel in her laboratory placement. In fact, the idea that scientists did not work in isolation was something that Isabel developed a new appreciation for during the AESP. She self-described the ways in which she collaborated with others in her laboratory.

At first I worked with Kevin and Kevin only. The grad students were there just doing their own things, [but] towards the end, we would help them along in some of the parts of their experiments. Like we helped them... set up a PCR and they also helped us in doing Kevin’s project. (I3)

Being treated authentically

Kevin treated the high school students in ways that represented varying levels of authenticity. He recognized that they were contributing to his research in meaningful

ways. They were not burdensome to him and he treated them accordingly. Kevin put it best in his own words during an interview.

So it was actually a benefit for me to have them help because they were an extra pair of hands that could help do things like subculture fungi or even plate. You know, I would sit them down and they would sterilize their hands, work in a sterile hood, and I would say, “you to put all these pieces of wood in this order”, and they did all of the sterilization. They did the processing, and they did the plating, which was huge for me to be able to back off and go work on something else while they were doing the legwork of the research. They were certainly not a hindrance at all. They were a big help. (MI2)

That being said, Kevin had former experiences as a high school science teacher and would often treat the program participants like high school students rather than authentic scientific researchers. For example, Kevin recognized that these high school students lacked the experience they needed to write successfully. He therefore took on the role of a teacher and devoted a large portion of laboratory time to helping the students with the written products required of them by the program itself. In fact, during multiple weekly laboratory observations, the students would be working on computers editing their research papers based on feedback they had received from Kevin. This took away from time that they could authentically participate in the research of the laboratory.

[Their] writing was really pretty bad... It's a new way of writing. The way they would present the data and explain things is a certain way. I think they should have had a class once a week on how to write science. (MI2)

Feelings of authenticity

Isabel was very interested in her project. This interest was related to how she felt like she was participating in authentic scientific research. “I’m actually doing the work and they aren’t really just telling me like what you’re going to do. I’m actually doing it firsthand” (I2). She did not always feel this way however. In fact, during her first semi-

structured interview, Isabel said that she felt like she was doing non-important tasks in the laboratory alongside the work that more meaningfully contributed to the overall project.

I feel like something in between [a visitor and a contributor]... We do like lame little stuff. Like clean the little plastic [parts] around the Petri dishes... But, also we helped along with the PCR... what they're actually working on... We contribute to their work. (I1)

As time went on, Isabel recognized that the work that she was doing was the same work that would have been done in the lab had she not been there. This contributed to her feelings of authenticity and her identity formation as a scientist. In her own words, Isabel said, "Like they don't have a separate experiment for us. [We] actually do their experiment. I guess they can trust us a bit, because we know what we're doing" (I2). However, nowhere in any interview or observation did Isabel refer to her experiment as her own, but rather always as "their project" or "Kevin's project" (I3). Perhaps Isabel never took full ownership over the project she was working on.

Kevin himself considered Isabel and the program participant working with her as "visiting researchers". He felt that they were to a certain degree authentic participants and thought that they might have picked up on the way that he felt about them through how he treated them.

I was considering them as visiting researchers. That's how I tried to approach it. Someone coming from a different background that had to be brought up to speed on what our projects were... I wouldn't be surprised if they felt to some degree that they were taking ownership of that idea that they were not just there to take up space, but they were there to get immersed and experience something that they were an active part of. (MI2)

Summary

Isabel experienced some growth in her understandings of the creative nature of scientific knowledge, the subjective nature of scientific knowledge and the tentativeness

of scientific knowledge. These changes can likely be attributed to her authentic involvement in a consequential research project and the activities and conversations that she engaged in with her mentors. For example, Dr. Barry had Isabel participate in a literature search that he knew would yield uncertain results. He then held conversations with her about how scientific knowledge is not really fixed like it is portrayed in a textbook. Perhaps this positively impacted her understandings of the tentative nature of science as the activity contained explicit messages about this NOS aspect. Additionally, Isabel was involved in a highly collaborative and social laboratory environment. She experienced first hand the subjectivity involved as her mentors applied creativity to account for the results that they obtained.

Isabel's naïve understandings of the myth of the scientific method were reinforced through what she experienced in her laboratory placement. As a result of reflective journal prompts, Isabel was attentive to the methods employed in her research setting.

I [had] like little checklists in mind to see if it really is, like if it really was true that they do use [the scientific method]. So I did observe...I thought he [Kevin] would skip the hypothesis, like the hypothesis part. We actually did make one and he continued like throughout the whole steps in order. (SI2)

When what she observed in her laboratory was a strict application of the scientific method, her understanding that all scientists really did employ the method was confirmed. Perhaps this was not a message that Isabel's mentors intended for her to receive. Consequently, explicit conversations regarding the relationship between research questions and methods may have been beneficial for Isabel.

In summary, reflective journal prompts encouraged Isabel to reflect about the implicit messages that she was receiving in the laboratory. Additionally, Isabel

experienced some explicit interactions with her mentors that may have positively impacted her understandings about certain aspects of NOS.

Tom's Story

Background

Tom came to the AESP with little to no prior experience in research science. He had completed a number of science fair projects in both middle and high school, but said that, "that's really the extent of science that I've had outside the classroom...I've never really gotten this involved with science before" (I1).

Tom entered the program as a rising junior in high school. His freshman year he successfully completed an honors biology course and during his sophomore year he completed a pre-IB chemistry course. He said that the, "chemistry course taught me the most" and he believed it had prepared him most for his participation in the AESP (I1). However, he acknowledged the limitations of his preparation for what he was currently experiencing in the AESP.

This kind of thing that I'm doing now is really specific on the molecular side of biology with lipids and proteins, which I haven't really gotten to study at all. It's a study I've done on my own. And then with the machines and the techniques, you don't really learn this stuff in 10th grade chemistry. (I1)

Tom understood that he was learning things in the AESP that he had not previously encountered in his high school science coursework.

Additionally, he felt that the laboratory work he had participated in during high school was significantly different from what he was experiencing in the AESP.

The main difference is that in high school when you do lab research, the teacher and you pretty much already know the result. With this kind of research, you have spontaneous discoveries throughout the day. You don't really know what's going to happen in the lab. (I1)

Tom then was readily able to recognize that school science was largely inauthentic when compared to the work of professional science.

Tom entered the AESP with a desire to pursue a science-related career. Specifically he said that he planned to major in chemistry during his first semi-structured interview. Although Tom did enter with a relatively firm commitment to a science major, he left the program with a newly found desire to become a research scientist.

I have never experienced that. I mean I've been in a high school little lab with papers that we have to fill out for lab completion, and this being in a big lab and doing the actual research and collecting data has really put me in the shoes of an actual researcher and it's been an attractive occupation for me now. I mean it's kind of the career path that I'm thinking. So it's kind of influenced sort of where I may go in life now such as job wise. (I2)

Tom was a member of the implicit seminar and was not placed with any other program participant in his laboratory group.

Laboratory description

Tom was placed in a biochemistry laboratory housed within the chemistry department during his apprenticeship. He was mentored by Lisa, a graduate student working in Dr. Carter's laboratory. Lisa described her own role as being "more of a mentor I guess than a teacher. A mentor in that I would say like 'hey, I am doing this with you it's not that I'm doing this for you'" (M12). Dr. Carter described her role with Tom as being "very distant" and "very hands off" (M11). That being said, Tom described multiple occasions where he interacted with Dr. Carter and asked her individual questions about his project. Tom worked in a large laboratory that actually housed two research groups. As such, he was able to interact with a wide range of graduate students with whom he was particularly social. In fact, each day Tom would take the time to join in a "daily cup of tea" break with the members of both laboratory groups

(O4). During one laboratory visit, Tom was observed getting a glass, cleaning it and making himself a cup of tea at the request of some graduate students in the group (O4). Tom did not expect this level of socialization as he entered the AESP. He described his PI mentor, Dr. Carter, and the laboratory environment itself as been very “laid back” (I1).

I probably did not expect her to be so laid back in a way. But I mean this whole chemistry department, not just Dr. Carter seems to be a lot more laid back than I thought... I mean like she has music playing in there and they're [the graduate student researchers] just kind of chilling sort of thing and they get their work done... I don't really want to be in a working environment where it's just cutthroat all the time... I would rather be, hey let's work together; everyone is friends in the lab. I mean that's the way I see it around here which is good. (I1)

Tom's analysis of the laboratory environment where he was placed was confirmed during each laboratory observation that was conducted during the AESP.

As Tom described above, although the laboratory environment was a very social one, it was also very productive. During each of the six observations, the members of the laboratory group, Tom included, were always at work on a research related task. Tom specifically was often on the move as he worked on his research project. He was observed in an analytical laboratory in another building preparing buffer solutions one day (O1) and observed working with analytical chemistry equipment in the main laboratory room during subsequent observations (e.g. O2). There really was not much down time in the laboratory that was observed.

Project description

In his project, Tom investigated the efficiency of a specific lipid transfer protein as he varied the pH of the system. He did this through an application of SPREE (surface plasmon resonance enhanced ellipsometry) analysis techniques. SPREE analysis involves directing a laser beam through a prism onto a gold foil surface to detect the

thickness of a coated lipid bilayer. The protein is then added and the time that it takes for the lipid bilayer to be removed at various pH levels is measured. A deficiency of the lipid transfer protein that Tom was researching is the cause of Tay-Sachs disease, a genetic disorder where gangliosides accumulate in the brain leading to premature death in young children. Tom's work could be significant in developing further understandings related to this disorder that currently has no known treatments. He won an award from the AESP for the best presentation of his research findings.

Changes in NOS ideas

Tom's responses to the ISS revealed no changes in his understandings of specific NOS aspects. However, corresponding interviews about those responses revealed positive changes in his understandings of the empirical nature of scientific knowledge (Table 4-9). Although Tom's understandings of the myth of the scientific method were informed both at the beginning and the end of the AESP, it is clear from survey interview data that very early in the program, Tom had experiences that may have impacted his understandings of the scientific method. It is not out of the realm of possibility that his view related to this aspect was positively impacted as a result. Table 5-4 contains representative excerpts from these data sources for Tom that illustrate his pre-experience views and his post-experience views related to both the empirical nature of science and the myth of the scientific method.

Self reported changes in NOS ideas and corresponding influencing factors

When Tom was asked to share the ways in which his ideas about science had changed during his participation in the AESP, he identified new perspectives related to the tentative nature of scientific knowledge, the subjective nature of scientific knowledge and the myth of the scientific method in addition to a newly found appreciation for the

social and collaborative nature of scientific work. However, according to the written science survey and corresponding science survey interview data, Tom's related NOS ideas were informed both at the beginning and at the end of the program. Potentially, his views at the end of the experience were even more informed in these NOS areas than they were at the beginning. It may be that such changes were not evident through the use of the science survey data and that the power of this data source was limited as a result. When Tom's mentors were similarly asked if they could identify any changes in his NOS ideas that they perceived over the course of the AESP, they were unable to provide any examples. Lisa said, "I've never spoken with him about that" (M12). Attention is now turned briefly to Tom's self-identified NOS changes related to the aforementioned NOS aspects.

Tom said that he entered the AESP with the understanding that the outcome of his project would already be known. "Well my old thinking, with the whole makeup an experiment knowing what is going to happen sort of thing is a lot different here as I've seen firsthand with what I'm doing... You don't really know the expected outcome" (I2). Tom continued to say that "there are really so many mess-ups within science and it really doesn't turn out so beautifully as you think it would" (I2). Statements like these indicate an informed perspective related to the tentativeness of scientific knowledge. Outcomes of Tom's project were unknown and were not firmly established. He described specific unexpected outcomes he obtained through his research when discussing the tentativeness of his findings.

The results don't always turn out the way you want them to... You can discuss more future work... In a high school lab you really can't [discuss future work] because everything is planned out. You hypothesize something and that's what happens. There's not much to discuss. So being able to

actually see some real results that work out in a weird way is interesting.
(I3)

Tom's self-reported changes regarding the tentativeness of scientific knowledge were related to his informed perspectives of the subjective nature of science which he also self-identified as having been impacted through participation in the AESP. Tom's informed perspectives are indicated in the following interview quotes.

I was actually able to do data collection and see for myself that it's not always clear cut and you don't always know the exact reason behind the result. So I was able to experience that with the data and I actually had quantitative data in way that allowed me to see that things aren't always straightforward [in how you interpret them]. (I3)

Tom echoed this statement in a later interview when he said, "Results don't necessarily come clear cut. You don't know exactly what happened. Conclusions that are made are definitely [tentative] and another conclusion could be made off of it [the same results]" (SI2). He experienced first hand that different interpretations can be made from the same pieces of evidence and that therefore conclusions in science are tentative by their very nature.

Tom also believed that his understandings of the myth of the scientific method were "somewhat new" (I3). He said that what he experienced in the AESP stood in stark contrast to what had "always been driven home" through school science fair projects where "you follow these steps... and you have this certain format" (I3).

Finally, Tom felt that he had come to appreciate the social-collaborative nature of scientific research in a way that he had not previously understood. He said as early in his first interview that, "I thought it would be a lot more serious in the labs... just really no communication. You don't see each other. Just do your thing. But it's not really like

that at all” (I1). In other interviews, Tom emphasized the “laid-back” atmosphere and that “scientists are relaxed in their work more than I would have thought” (SI2).

Tom was also asked to identify what parts of the AESP had influenced in NOS ideas. Tom very clearly indicated that the laboratory placement rather than the seminar or interactions with other program staff were the sources of any changes in his NOS ideas that occurred.

Definitely the laboratory. Just being in there every day and just seeing that scientists are just normal people. They just come in, turn on their music, and get to work. I mean they’re always on their computers looking at graphs and having discussions based on those graphs. Yeah you’re doing experimenting here and there, but analyzing data, that’s a big massive portion of it. (SI2)

Tom described scientists as normal people who spend most of their time discussing with others how to analyze data. Observing this occurring regularly in his laboratory placement was according to Tom one factor that influenced his NOS ideas.

Authentic action

Tom was involved in some aspects of his research that could be described as authentic action and others that were more representative of inauthentic action. In regards to inauthenticity, Tom was not involved in any of the design of his project or in any subsequent modifications of the procedures. In fact, during laboratory observations, Tom would wait for Lisa to arrive and give him clear instructions before he would manipulate any of the equipment or perform any data collection task, even simple ones. Lisa described Tom’s contributions to the project as follows.

It [the project] was pretty much set before he came. You know it was something that I had to do. And I had done the preliminary work before... So I guess I didn’t give him a chance [to make any decisions] because I new exactly what it was we needed to do. (MI2)

Tom himself recognized that he was not being involved in the development of his project early in the AESP. According to him, “I’ve never really voiced my opinion...It’s one [a project] that’s already setup... So I’m not really having a say in what we’re doing” (I1). Tom continued to describe specifically how he was not making any decisions during his time in the laboratory. “Maybe plugging in a machine... that’s probably the extent of it, but I’ve never really made any groundbreaking or even day to day decisions” (I1). He even described an occasion where he made a suggestion regarding the relationship between pH and the significance of the research relating to Tay-Sachs disease that “was shot down more than anything” by Lisa (I1).

However, Tom had a clear understanding of the development of the project even though he was not around for its conception. Tom said that his project was an “on going process of determining more about this protein... so we’re building on other people’s research to find out our pH levels, and then people will be building off of that” (I1). Based on statements such as this, Tom had an informed understanding of why he was not involved in the decision-making regarding the design of his research project. In fact, looking into the research literature that served as the basis for his project helped to stimulate his interest in the project in the first place.

The first couple of weeks, I was just kind of going with what Lisa said, kind of nodding my head, but now I’ve actually read the journals. I know what we’re doing, what the purpose is behind it. It enables me to actually enjoy it more. (I2)

Although Tom wasn’t involved in authentic design or decision-making, he was involved in authentic data collection and analysis of that data. Tom said that it was “pretty cool that I’m contributing” and that “I’m able to jump in” when talking about the early data he was obtaining (I1). The authenticity of the data that Tom was collecting

and analyzing was due to its value to his laboratory group. Lisa said of Tom's work, "This is his contribution to the overall project and I'm not going to redo it" (MI2). This speaks to Lisa's trust in the quality of the research that Tom was engaged in. Lisa also said of Tom's work that it "will go into my dissertation" (MI2). Dr. Carter herself described that while Tom's actual data would not show up in papers, it was "definitely key" to Lisa's research and was something that Lisa would have had to do if Tom had not been there (MI1).

One other aspect of authentic action that Tom was engaged in was collaboration within his laboratory group and with other laboratory groups in the chemistry department. Tom described his work as being "more of a team sort of thing... seeing all the labs that intermingle with each other. I would say the whole chemistry department is pretty much like a whole team" (I2). Tom specifically discussed occasions where he needed to interact with graduate students from other research groups to reserve and share pieces of laboratory equipment. Additionally, Tom saw collaboration occurring as he prepared his paper, poster and research presentation to disseminate his results. "Definitely the collaboration with Lisa [increased] based on putting together the research paper and the poster... editing and revising it" (I3). Finally, Tom was able to attend weekly research group meetings where graduate students would present their findings. He felt like his attendance at these gatherings where he had the opportunity to witness first hand collaborative critique of presentations had impacted the way in which he presented his own research. During the last two laboratory observations, Tom was observed working with Lisa and other graduate students on how to best graphically represent his data during his own research presentation.

Being treated authentically

Like the levels of authentic action Tom engaged in, he was treated by his mentors and other members of his laboratory group in some ways that were authentic and other ways that were less than authentic. The relationships that Tom built in his laboratory group were quite genuine. He described making a number of close friends with graduate students in the laboratory including his own mentor. He felt like he was included in a way that a typical high school student would not have been. On multiple occasions he brought up the friendship building that occurred through having morning tea with the graduate students each day.

However, Lisa never really treated Tom like an authentic member of the laboratory group. In fact, Lisa said that when she found out she would be mentoring a high school student in her laboratory she “was pissed” (MI2). She said that she felt like she was “going to babysit for seven weeks” (MI2). She did acknowledge that “in the long run he helped me, but it just took you know with him there, it took five times as long as doing it myself” (MI2). She continued to say that she would not mentor a high school student again and that “in hindsight, I would have gotten more done [without Tom]” (MI2). On multiple lab observations, Lisa was observed getting visibly frustrated with Tom and the mistakes that he was making as he prepared solutions and ran tests on the SPREE equipment. In summary, Lisa never treated Tom like anything other than a high school student and she did not seem to genuinely value his presence in the lab. For these reasons, she did not treat Tom in a fully authentic way.

Feelings of authenticity

Tom’s feelings of authenticity developed over the course of the AESP. During his first semi-structured interview, Tom said he felt “probably in between” a working

contributor and a visitor to the lab. He continued to say that, “I haven’t really done any work myself. I’ve kind of just watched Lisa do things... but I think later on in the project she’ll start to trust me more” (I1). He also said in this first interview that “as time moves on, I’ll be just as much a contributor as any of the other Carter group people” (I1). By the time of the second interview Tom felt like he was a working contributor to his laboratory group. “I’m doing as much as she [Lisa] is doing now. I mean, I’ve observed her and I’m just as adequate as she is” (I2). Tom then felt like the work that he was doing in data collection and analysis was authentic and that he was an authentic member of his laboratory group as a result. Lisa said that she believed that Tom thought he was a working member of the laboratory group and that he was more than a visitor, although she never treated him as one.

Tom felt like he was a working contributor even though he did not fully understand the value of the data that he was collecting. This feeling contrasts with that of both Lisa and Dr. Carter who trusted the quality of the work that Tom completed and understood its role within Lisa’s dissertation research. Tom, however, thought that the project was tailored to him as a high school student and did not know whether or not his results were useful to anyone. Tom expressed this feeling in the following interview excerpt.

I’m pretty sure it’s [the research project] just for me... because it’s not too complex...It is designed so a high school student could understand it... but I don’t think [the results] are going to go anywhere. Maybe, I’m not sure. (I3)

Summary

Tom was a unique participant in the study. He entered the AESP with relatively informed views of NOS according to his pre-survey. However, it seems that some of these informed views, particularly his perspectives regarding the myth of the scientific method, may have been impacted very early on through his participation in his

laboratory setting. This was the case even though the authentic action that Tom participated in was limited in the sense that he had no input into the design or the modification of the procedures that he used to collect and analyze data. That being said, Tom did have an informed conception of the development of his research project. Additionally, according to Tom, Lisa had explicit conversations with him regarding the lack of necessity for having a hypothesis when conducting scientific research (Table 5-4).

Tom's perspectives regarding the empirical nature of scientific knowledge were positively impacted as a result of his participation in the program. Perhaps this can be attributed to the levels of authenticity in data collection, analysis, presentation and collaboration that Tom experienced in his laboratory placement.

Finally, although Tom did not understand the value of his results and was not treated in a fully authentic way by Lisa, he left the program feeling like he had become an authentic member of his laboratory group. Perhaps this was due to the acceptance he received from others in the group during his apprenticeship.

Jennifer's Story

Background

This was Jennifer's first experience participating in authentic scientific research. Jennifer's father, a medical doctor, was himself a participant of the AESP as a high school student. Her family had very strongly encouraged her to pursue a science related career. At the beginning of the program, Jennifer desired to attend medical school and then to become a medical doctor. Her future plans remained unaltered during the duration of the AESP. During her first interview, Jennifer stated that research science was not for her. That being said, she felt adequately prepared for her participation in the

program this summer as a result of her high school science coursework. She had already taken biology and chemistry through an International Baccalaureate (IB) program at her school. Jennifer enrolled in and was a member of the explicit/reflective seminar.

Laboratory description

Jennifer worked in a laboratory that investigated plant evolution. Two principal investigators (PIs) that happened to be married to each other operated the laboratory. Jennifer was herself primarily mentored by Fred who was a doctoral graduate student working under Mrs. Dr. Jones. Jennifer was paired with another participant of the AESP. Additionally, a third high school student was volunteering in the laboratory over the summer. The laboratory group itself was a very large group. The atmosphere of the laboratory was one that was both serious and quiet as researchers went about their work diligently. The laboratory had typical biotechnology equipment dispersed throughout the room including an incubator, thermocyclers, centrifuges and a plethora of equipment for pipeting. There was an expectation among the laboratory group for members to present at major professional conferences. As a part of this, there were multiple lab group meetings that Jennifer and the other high school students attended where graduate students gave their presentations and were provided feedback.

Project description

The purpose of Jennifer's study was to determine which genes were responsible for the development of the pitcher leaves of a carnivorous plant. She conducted this research by performing polymerase chain reactions to isolate and amplify the genes under investigation. These genes were then sequenced and compared with other gene sequences in order to identify them. She enjoyed participating in this research. Early in

the experience, Jennifer stated, “Working with it [PCR equipment] just blows my mind” (I1). Jennifer’s project was funded through part of a grant that Fred had written. The data that were collected and analyzed will ultimately end up being part of Fred’s dissertation.

Changes in NOS ideas

Analysis of Jennifer’s written science survey data revealed growth in her understandings of the empirical nature of scientific knowledge, the subjective nature of scientific knowledge and the tentative nature of scientific knowledge. However, on her corresponding survey interviews, the only exhibited growth in NOS ideas was related to Jennifer’s understanding of the subjective nature of scientific knowledge and the myth of the scientific method (Table 4-9). Table 5-5 contains representative excerpts from these data sources for Jennifer that illustrate her pre-experience views and her post-experience views related to each of the aforementioned NOS aspects including those that were only revealed to change through the written science survey data (i.e. the empirical nature of scientific knowledge and the tentative nature of scientific knowledge).

Self reported changes in NOS ideas and corresponding influencing factors

Throughout the experience, Jennifer thought that her understandings of NOS most likely had not changed. She said, “I guess everything [my understandings of science] stayed the same...it probably stayed the same” (I3). However, in her final interview, the post-science survey interview, Jennifer acknowledged the possibility that some of her views about science may have changed over the course of the summer.

It think for some of it, it was the exact same thing, but I’m pretty sure there have been some changes. Probably just because I never really thought about anything this way until like I had these interviews and stuff. So I

guess like I've become more aware of different views. And I thought about it and I guess like just when the question was asked, like I think differently about it. (SI2)

However, Jennifer was unable to precisely pinpoint which aspects of NOS she understood in a different way at the end of the experience. That being said, she did say a few things that hinted at growth in understandings related to the myth of the scientific method in her semi-structured interviews.

We had like a path we were going down, but because things weren't working out we had to change things and go back and fix things. Try things out, see what works. So that's a change in the process...I didn't necessarily expect it. (I2)

She also expressed a newly found awareness related to the tentativeness of scientific knowledge.

I guess like all of our PCRs like...I don't know if we should call them failures, it's just we don't know exactly what happens, so we're not like certain why it happens, so we just have to play around to see what will happen...you're never quite sure. (I2)

When the PI and the graduate student mentor were asked about whether they thought that Jennifer's understandings of NOS may have changed over the course of the experience, they both described the possibility that her understandings of the collaboration involved in professional science may have changed.

We kind of feel like the lab is kind of a big family. I guess, certainly something they [Jennifer and the other program participant] would have seen if they wouldn't have consciously picked up on it is that science today at least is not a single individual sitting in a corner, that there is a social element. (MI1)

Fred, Jennifer's graduate student mentor, also indicated that perhaps the social-collaborative nature of the laboratory in which Jennifer was placed might have impacted her understandings of NOS.

Because ours is also kind of a different lab than that, we have like two PIs that are in charge of it and I don't know, I guess you usually just think of this one professor guy at the head of the lab like bossing everybody around, but with our PIs, I don't know if that changes their perception...how that professor shares his work and stuff like that. (MI2)

Although changes in Jennifer's understandings of the social-cultural embeddedness of scientific knowledge over the course of the experience were not detected (she was rated informed both before and after the experience), her understandings of the subjective nature of scientific knowledge did appear to change. Perhaps these changes in Jennifer's understandings of the subjective nature of scientific knowledge were related to the changes in NOS understandings that were reported by Jennifer's mentors.

Jennifer was asked to describe any factors that she thought might have influenced her understandings of NOS ideas. She specifically mentioned during one interview that apart from the surveys and the interviews, she had not spent much time thinking about these ideas. "I think it was just like these survey and the interviews. Just because like every question is kind of like stuff that you don't really think about and question" (SI2). She also discussed how at other times throughout the experience the reflective journals and her participation in the explicit/reflective seminar were influential in shaping her NOS ideas. Jennifer did not think that her experiences in the laboratory played a role in changing her perspectives regarding NOS. "There was never a time in lab where I thought really...I just had an epiphany like oh what about this?...I never thought about it [NOS]" (SI2).

Authentic action

Jennifer participated in action in the laboratory that could be described as being authentic in the degree to which it resembled the practices of professional scientists. In professional practice, the scientist is involved in the development of a research question

and the methods used to carry on an investigation. In the case of Jennifer, Fred alone both designed and developed Jennifer's research project. In those aspects, Jennifer made few significant contributions to her project. That being said, she did have some limited opportunities to make day-to-day decisions regarding how to go about individual experimental trials. This was observed by the researcher when visiting Jennifer in her lab and echoed by Jennifer in her own words during interviews.

This was a preplanned project. My grad student got a grant for this project. So you can't really change anything about it. Like I guess we changed a few things like if a PCR doesn't work we change something for the next round of it, but over all it's gonna follow whatever route the grad students wants to take it because it's his project. (I1)

Later on in the same interview, Jennifer described how she was involved in collaborative decision making with her graduate student mentor when certain experiments needed to be modified.

Our grad student Fred will talk to us about it [the necessary modifications] and we all decided together what to do...like today we just completely came up with a new idea of what we can do to test something. We did like this experimental PCR today and we all came up with it together. (I1)

Jennifer then was involved only to a limited extent epistemically in the design of her research project, but did play a part in daily modifications to the methods she used to investigate her question.

Related to the authentic action Jennifer experienced in her laboratory investigation was the collaboration that was present in her placement. This collaboration was evident in the way that graduate students worked with each other in the laboratory, but also in how the high school students worked together. As was previously mentioned, Jennifer was placed with another participant of the authentic research program in her laboratory. This naturally increased the amount of collaboration that Jennifer experienced when

compared with other case study participants who were placed in laboratories with no other high school students. In fact, collaboration was something that was observed during every laboratory visit made by the researcher. Jennifer would often work collaboratively with the other high school students as they discussed how to set up their experimental trials. During one observation, the researcher noticed the program participants sharing with each other what they had recorded in their laboratory notebooks (O2). They also were observed discussing how to analyze and present their results. In an interview with Dr. Jones, she explained the importance of collaboration as an authentic component of scientific practice for her personally.

I guess I try to bring lots of different perspectives to bear on a single question...A lot of times in order to get these multiple perspectives you need collaboration because we don't all have all the tools to get all the views. (M11)

Dr. Jones' perspective regarding collaboration was a reality in her laboratory and was experienced by Jennifer and the other high school student apprentice placed within it.

In addition to this collaboration, Jennifer was a part of a laboratory group that as a whole was constructively critical of each other's work. During one observation, the researcher had the opportunity to attend a weekly laboratory group meeting where members of the group were sharing presentations that they were going to give at an upcoming international conference. Jennifer herself recognized the importance of these meetings. She said, "their conferences are really important and they all gave their opinions to try to help them make their presentations as good as possible" (I2).

Jennifer and the other high school student that she was working with were also observed learning from other members of the laboratory group how to share their findings in effective ways. On one occasion, Fred walked the high school students down

a hallway where posters were displayed so that the students could learn from past research how to effectively present genetic research results. Jennifer recognized the value of learning from past research and said that what had been done previously in her laboratory was “helpful to our study” (O3). This group critique of work and learning from what had gone on in the past is representative of authentic action taken by professional scientists.

Being treated authentically

Jennifer believed that her mentors throughout the research experience were treating her in authentic ways. Such feelings were validated during laboratory observations. For example, Jennifer’s mentors allowed her and the other program participant to work independently. This seemed to be indicative of the levels of trust they had for the work of the participants. Jennifer herself described how this independence occurred through a gradual release of control from the graduate student mentor to those being apprenticed.

At first he [Fred] was taking us step by step through everything, but now he just tells us what to do and he goes and works on something else and then we do everything, and everyone in the lab is doing all their things at once.
(I1)

It should be noted, that this quote was taken from the first interview that was conducted early on in the experience. Therefore, it did not take long for Jennifer to begin to be treated authentically by Fred. Fred described his role in the following way: “I guess it was kind of like a mentor...I don’t want to say boss, but I was like the person who gave them instruction on a daily basis of what to do” (MI2). Fred then viewed himself as a mentor who did give instruction but who did not order his students around.

Not only did Fred allow the students to work independently as they collected data, he also allowed them some autonomy as they analyzed the data they had collected. This was observed as Jennifer and the other program participant placed with her were working using computer databases to sequence genes. Fred was observed allowing them the freedom to come up with their own interpretations of their experimental results. Fred himself alluded to the idea that he thought of Jennifer and the other program participant as members of the laboratory group when he said, "They got their own name tags, so they were like a part of us" (MI2).

Both Dr. Jones and Fred valued the work that Jennifer and the other program participant were doing this summer and were able to recognize the contributions that the research was making. This clearly came through in talking with Dr. Jones.

On what they got, you know they were able to find a few of the sequences that they were, that he [Fred] was looking for and he is going to be able to include those in his work. So I think that they really provided some information, I think it also showed maybe which places that he thought might work wasn't going to work and so he can adjust from there. (MI1)

Fred also recognized the value of Jennifer and the other student. He had confidence in the quality of the data collected and the results that were achieved by Jennifer. He also felt that this quality was directly related to his abilities as a mentor to prepare them to work so effectively in the laboratory. He said, "I kind of trained them in how to do it and they understand the project pretty well. They're really valuable workers. I'd like to keep them on at some point" (MI2). This recognition of the value of Jennifer by Fred was directly related to her being treated authentically. Jennifer and the other program participant gained the trust of their mentors and therefore were allowed to act in relatively authentic ways.

Feelings of authenticity

Jennifer herself felt like an authentic member of the laboratory group in which she was placed. From the very beginning she felt like she was a contributor in her laboratory placement. “I think I’m like a worker in there because we’re doing our grad student’s project” (I1). In other words, Jennifer felt like she was doing authentic science and therefore she felt like she was an authentic worker. Dr. Jones described how she thought that Jennifer probably felt like an authentic member of her laboratory group.

I mean they knew I think that what they [Jennifer and the other program participant] were doing was real science. That it wasn’t something we just kind of say “Oh, you know, here go play with this”. That it was really something that was important for Fred’s project and so hopefully they felt like they were you know, real members of the lab and not just visitors who were here to learn how to do this but to stay out of the way. (MI1)

Dr. Jones was correct in thinking that Jennifer recognized the value of the work that she was doing. She was quite eloquent in her description of the importance of her research project and related it to the novelty of the work.

So no one really before this project particularly knew what genes did what. So part of this project is finding out what genes are actually affecting the leaf development, which these genes are. So that is just plain new information and not just new to the scientific community. So that will help out with other projects dealing with anything related to this. (I3)

Jennifer’s sense of being a contributing member of the group increased over the course of the experience. In one interview she mentioned, “Since the beginning it [her comfort in the lab] has gone up. I feel like I belong there” (I2).” Later in the same interview she attributed this sense of belonging to the amount of time she had spent in the lab. She said, “Just the more time spent there the more I feel like I’m supposed to be here” (I2).

Jennifer's feelings of authenticity were directly related to the identity that she developed of herself as a scientist. It is believed that these feelings were related to the ways in which she was treated authentically by her mentors and that as a result the implicit messages received through her authentic action in the laboratory impacted her NOS understandings.

Summary

Jennifer was part of the explicit/reflective group and was working in her laboratory with another participant of the AESP. Some of her views about NOS were impacted over the course of the experience. However, her views about the relationship between theory and law were not impacted even though she was a member of the explicit/reflective seminar where views related to this impact of NOS were significantly and positively impacted for the group as a whole. Jennifer did not encounter anything in her laboratory placement to challenge her perspective regarding this aspect. It could be that for Jennifer, her changes in NOS views were the result of a mixture of the implicit messages that Jennifer was receiving in the laboratory and the explicit experiences she had in the seminar itself, and that only when these two sources of information were aligned, did her views change. For example, Jennifer's views on the empirical nature of scientific knowledge, the subjective nature of scientific knowledge and the myth of the scientific method were positively impacted in ways that seem linked at least in part to experiences in the laboratory itself in addition to activities presented in the explicit/reflective seminar. Because Jennifer's mentors were not observed engaging in any explicit NOS conversations with her or the other program participant in her laboratory, changes due to laboratory participation were most likely the result of implicit

messages. However, Jennifer did not recognize the laboratory as a source of any changes in her NOS ideas.

John's Story

Background

John was a Hispanic student who received a scholarship to attend the AESP. He had participated in a science fair during his freshman year of high school, but other than that had no prior experiences conducting scientific research outside of a formal school science context. He described high school coursework that he had completed in biology and in chemistry but felt that he was not as prepared for the program as other participants who had already successfully completed advanced placement science classes. John discussed how he would ask questions to other more knowledgeable participants in the program. "I'm like always going to her [another program participant in John's laboratory], like what does this mean? And she already knows what it means" (I1).

Related to John's perceived lack of science content knowledge was his self-described "frustrations" with science in general at the beginning of the program. John said, "In high school it's like little by little by little, I lost interest in science. I don't know why, I guess it's because I get frustrated sometimes" (I1). John said that in high school he would try to read something from his textbook and then not understand what he was reading and subsequently would fail a quiz in science. He contrasted this school experience with what he was encountering at the AESP very early on in the summer. "Over here, I read something, they [my mentors] talk to you about it, and if you get it wrong, it's okay and they explain it" (I1). John thought that he learned a lot of scientific

content knowledge through the mentorship he received in the AESP and was less frustrated with science as a result.

A consequence of John's lessened frustration with science was a renewed interest in pursuing a science related career. At the beginning of the AESP John said, "I want to do something in the medical field, but I'm not really positive about that, because sometimes... I don't understand some things and it gets frustrating... sometimes I want to go into criminal justice" (I1). John's frustrations with science pushed him at times into considering careers outside of the realm of science. However, at the end of the AESP John self-described a renewed commitment to a science related future particularly one that involved a focus in scientific research.

It [the AESP] was wonderful, amazing and I would do it again and I will stick to science... I didn't know if I wanted to study science in college... I just want to do research [now] and I want to be able to experiment... especially in animals. That will be interesting. I like learning about why they do specific behaviors. Not many people understand why. They just say, 'Oh. They do this', but they can't explain why. (SI2)

John was paired with another program participant in his laboratory. John found this arrangement to be valuable for a number of reasons. He described being able to go to this other participant when he had questions about content and appreciated being able to "figure it out together" (I2). Additionally, he appreciated the friendship that he developed with this participant and the informal conversations that he had with her during down times in the laboratory. He said that without her "I would have been bored out of my mind and I wouldn't know what to do" (I2).

John enrolled in and was placed in the implicit seminar. As such, he did not complete any reflective journal entries nor did he engage in any explicit NOS activities or related group seminar discussions.

Laboratory description

John was working in an animal behavior research laboratory through the biology department at the university where the AESP took place. He was mentored by Dr. Davidson, the PI of the lab, and Rebecca a graduate student working on her dissertation research under the supervision of Dr. Davidson. Much of the research that Rebecca was engaged in centered on the behaviors of Convict Cichlid fish. John's time conducting research was divided between work in a traditional laboratory room and a tank room that housed the fish that were under investigation. In the tank room, John and the other program participant placed with him would record observations of fish behavior in a variety of ways including video taping fish interactions. In the traditional laboratory room, computers were used to analyze data that were collected in the tank room. John experienced a laboratory environment that was very warm and friendly. On multiple observations it was noted that laughter was a frequent occurrence in the laboratory rooms. John described this atmosphere as being different from what he expected. "I thought it was just like going to work. Like you come and you do your stuff and then you leave and you report to your professor your findings. [However], it was such a friendly environment" (I3).

Project description

John's work was a continuation of Rebecca's research on the behaviors of Convict Cichlid fish. John set up a number of different nests for mating pairs of fish. These fish then spawned and the tanks filled with their offspring. A physical model of a predator fish was then manipulated within the tank and John recorded the number of times that the parent fish would attack the model as they protected their young. The behavior was also videotaped. John was then able to use computer software to explore the

relationship between this behavior and the specific architecture of the nest. Statistical analysis was performed in order to discuss the significance of the relationships observed. John won an AESP award for the quality of his research presentation.

Changes in NOS ideas

Out of all the case study participants, John's NOS ideas as revealed through the written science surveys were the most different from his NOS ideas as revealed through open-ended interviews regarding his written survey responses. Whereas no positive changes in NOS ideas were revealed through the written survey data, positive changes in John's understandings of the empirical nature of scientific knowledge, the creative nature of scientific knowledge, the social-embeddedness of science and the tentative nature of scientific knowledge were clearly observed through an analysis of his interview data (Table 4-9). Table 5-6 contains representative excerpts from these data sources for John that illustrate his pre-experience views and his post-experience views related to each of the aforementioned NOS aspects.

Self reported changes in NOS ideas and corresponding influencing factors

John thought that his NOS ideas had not been influenced by his participation in the AESP. When he was asked whether or not he had different perceptions of science as a result of working in the lab, he consistently said things like, "No, not really" (I1), "I'm not really sure. I don't think so" (I2) and "not really, I don't think so" (I3). He did say that the reason that he thought that his ideas had not changed was because "I haven't really thought about it" (I2). Had John been given opportunities to reflect on his NOS ideas, perhaps he would have recognized and self-identified the ways in which his perspectives regarding science were changing.

That being said, he did say that, “I just find it [science] more interesting” (I3). Additionally, he felt that “science is more, I guess broader, bigger” than he thought science was at the beginning of the AESP and that he thought the people in his lab “would be all professional and call each other by last names... but they’re like all friends... I didn’t know it was like that” (I3).

Although John was unable to recognize the ways in which his NOS ideas had changed, his mentors were able to do so. When Rebecca was asked if any of John’s ideas about science had been impacted, she offered the following perspective. “I think [John] would have got some of that aspect, kind of like the fluidity of ideas and how nothing is really concrete [in science]” (MI2). In one laboratory observation, Rebecca was actually observed as she explicitly discussed this with John. She said, “In science we are never positive. We can’t prove anything... there is always going to be other ideas” (O6).

Dr. Carter similarly was able to express some ways in which she believed that John’s ideas about NOS had been impacted. These changes in NOS ideas are represented in the following quotes.

He had no idea that there was the community that there is in the profession... that there was all this interaction, and sense of community and feedback. He had a little bit of the idea that you would be on your own. (MI1)

One of the things that I think [John] pulled together through the program was a sense of the narrowness of [his] hypothesis and [his] study and what can [he] infer from that. I think [he] got a better sense of that. ‘Cause science is very incremental and I think very few people who haven’t been in the process appreciate that. I think they have the fantasy that you do a study and you get all sorts of new insights. It’s not like that. Each study brings us a little closer to some insight. (MI1)

John's mentors believed that his understandings related to the tentativeness of science, the empirical nature of science and the social-embeddedness of scientific knowledge had changed during his participation in the AESP. His interview responses revealed that his understandings related to these NOS aspects had likely changed accordingly.

Although John did not believe that his NOS ideas had changed or at least was not able to identify how they had done so if they had, he did believe that his understandings of science had developed over the course of the AESP. He felt that such changes in understandings were impacted primarily by his experiences in the laboratory.

I mean we learned a lot from the seminar, but I feel like I have gained more knowledge from the lab. Just because you have personal experience and you're actually doing things whereas in the seminar you are kind of hearing someone explain it to you. I don't know, I feel like I learned more in lab.
(SI2)

Authentic action

Rebecca had designed the project that John was working on prior to the start of the AESP. So in that sense, John was not involved in an authentic way in the actual design of his project or the selection of the methods used to investigate his research question. Dr. Davidson acknowledged this when she said that John "participated in a study that Rebecca and I had ongoing and had planned" (MI1). John recognized that his project was preplanned. That being said, he still felt like he was making contributions. He felt that he had "contributed. But not with decision making, because she [Rebecca] already knows what she's doing. I haven't said, 'Oh we've got to do it this way'" (I1). John said that when he followed procedures in the lab he followed the instructions given to him by Rebecca without modifying them. "Well right now, I just follow whatever Rebecca has taught me to do. So when we measure fish, we do it precisely how she taught us" (I2). However, during one laboratory observation, John was observed making

a choice about which test he wanted to perform on the fish (O3). On this occasion, John decided to run a test using a model of a predator and then to record the ways in which the fish responded.

While John may not have had the opportunity to contribute significantly to the design of his study, the data that he was collecting were definitely of value to and usable by the members of his laboratory group. This is evident in the following interview excerpt from Rebecca.

There were one or two instances where I was like, 'Oh my god. Am I going to be able to use this?' Because there would be things like John would ask me the same question seven times and it would start to make me nervous... but then I would see other things where [John] would very diligently look at notes or you know double check things and so that made me less nervous... I mean I will use the data. (MI2)

While John was not involved to a large degree in the decision making process as the data were collected, he had opportunities to do so as data were analyzed for his project. Rebecca described how such opportunities were made available to John even if he did not take them.

I mean there were some places where I made [John] make decisions. Where I had preconceived ideas about the videos. Like I told [John] to watch the videos without telling [him] anything about what they were for or what I wanted to know, and I said, 'Hey. Watch this. What do you see?'... But in terms of if there was something that [John] thought of that I hadn't, I can't think of a specific example, but if [he] had thought of something that I hadn't have thought of that I would have thought would be useful I would have left it on the list. I just can't think of if that happened. (MI2)

John participated in a great deal of authentic action as he interpreted his results. Rebecca recognized the ownership that he took over his project as he did so. She talked about him being responsible for the project itself, the results that he obtained and interpreted and the way in which he organized his presentation. This really speaks to

the high level of authentic action that John was engaged in during his time in the laboratory.

But then as things kind of gelled in the last couple of weeks, and he was producing products that summarized his results, and interpreting what he had really found and not found, I think he kind of wrapped his head around it. And you could see that in his talk which he was later awarded for. Because he got it. He really got it. (MI2)

Finally, John was involved in collaboration with others during his authentic participation in the laboratory. This collaboration resulted in high levels of confidence on the part of Rebecca regarding the work that John had completed.

So as far as the results and the interpretations of those results, that part is done so collaboratively... They [John and the other participant placed with him] didn't do that part completely on their own. So I am not handed this thing that says this happened more than that and have no way of knowing how they got to that statement, because I helped them get to that statement... The data is usable and we can plug it into statistical analyses and say under this treatment this behavior happens more. (MI2)

Being treated authentically

Rebecca stated that she thought of John as a working and contributing member of the laboratory group. She said, when talking about the laboratory group as a whole, "We made a lot of effort to try and include them" (MI2). That being said, she did not treat John completely like an authentic member within the laboratory group. She recognized that the program participants placed in her laboratory were high school students and she felt the need to treat them accordingly. This can be seen in the following interview quote from Rebecca.

Working with high school students is definitely different than working with undergraduate students. Cause, with high school students I felt a little bit like for lack of a better word like a parent. There was a little bit more like I don't know discipline involved...there was always kind of a hierarchical structure and sometimes they had to be reminded of that. (MI2)

That being said, Dr. Davidson treated John just like he was any other member of her laboratory group. The following quote by Dr. Davidson is an indication of how she treated John in authentic ways.

There was a lot of back and forth in each of those times that I interacted with John about what he was doing and what he was finding and how he was interpreting it. And I would say that's the same role that I play with my graduate students. (M11)

Feelings of authenticity

John's feelings of authenticity developed quickly over the course of the AESP. He said the following during his first semi-structured interview.

At first I thought I was in between [a working contributor and a visitor]. Like my grad students didn't want me there. Like I was holding them back. But as we go on more in the lab, I feel like we're actually helping them a lot. (I1)

By the time of his second interview, John described feeling like a full working member of the laboratory group.

I mean I definitely before felt like I was helping them out, but I don't know I just felt like I was working for them. Now I actually feel like I am working with them. Like you know, we're all working together. We're all friends. Kind of lab mates I guess you'd say. (I2)

John believed that he could work in the laboratory independently by the time of his third interview and described the ownership that he had taken over his project that resulted in him feeling genuinely interested in what he was doing.

I got to the point that I could be in the lab without anybody there because I knew what I was doing. So I'm more interested in it now. I'm definitely excited and happy that I made this experiment. (I3)

Like before I kind of viewed Rebecca as kind of a teacher... Now it's more like we're partners and she supervises me, but I feel more comfortable around her, because I know I'm doing my own experiment. (I3)

Finally, Dr. Davidson believed that John had developed feelings of authenticity as he worked in her laboratory. She described the ways in which John was acting and how

those activities were no different than any other activity in which a working member of the group would participate.

I would say they felt like they [the AESP students in my lab] were working contributing members of the laboratory group. Both of them and John in particular. You know they participated in most of the activities we do in the lab. They went to lab meetings. They participated in taking care of fish. They worked on their data, they collected data. These are the same things they see Rebecca doing... They were really drawn right in. (M11)

Summary

Out of all of the case study participants, there was greatest amount of difference between how John's written survey responses and his corresponding interview responses were interpreted. John was much more comfortable talking about his beliefs about science than he was writing about them. Therefore, more weight was placed in his survey interviews than his written survey responses when examining his NOS ideas. Perhaps this speaks to a limitation of using open-ended written surveys such as the ISS with students who are apprehensive about their writing abilities.

While John's written surveys did not indicate changes in his NOS ideas, his survey interviews and other conversations held with him and his mentors did reveal changes in his understandings of many aspects of NOS. It is believed that the confidence that his mentors placed in him and the explicit conversations that they had with him about philosophical issues related to science in addition to the authentic action paired with subsequent feelings of authenticity experienced by John contributed to changes in his understandings of the empirical, social, creative and tentative nature of scientific knowledge.

In regards to the growth that John experienced related to his understandings of the creative nature of science it is worth mentioning that Amy, the other program participant

placed with John, experienced the same growth in her understandings of this aspect. This is particularly noteworthy considering that Amy was also a member of the implicit seminar. In her post survey, Amy wrote the following response.

Yes [scientists use creativity and imagination] because planning, experimenting and interpretation all are individualized. They are all done differently by different people. Example: If two people watch the same video of a fish and record the same behavior, they will for sure have different results. (S2)

This result lends credence to the power of the implicit messages that John received regarding the creativity involved in practicing science since both he and Amy displayed similar growth when placed in the same laboratory context.

Joseph's Story

Background

Joseph entered the AESP with a strong interest in science and significant experiences both formally and informally as a learner of science. However, he recognized that the AESP offered him an experience in authentic research unlike any he had previously encountered. Formally, Joseph had completed two years of chemistry prior to the AESP. His experience in advanced placement chemistry was one that he described as being very successful and that really sparked his interest in attending the AESP. Additionally, Joseph had attended at least one summer science camp between each year of high school. After his freshman year, Joseph participated in an aquatic science camp as well as an earth science camp. Through these experiences, Joseph engaged in learning science content but was not immersed in authentic scientific research. After his sophomore year, Joseph attended a nuclear engineering camp at a major research university where he studied nuclear science content and made a “very

simple nuclear reactor monitor” (I1). Joseph described this experience in the nuclear engineering camp as being very different from his apprenticeship in the AESP.

I did work in a laboratory setting, but I worked with kids who were in high school and they were not as mature as they should have been... I do feel like at this [research experience] you get taken a bit more seriously... [There] it felt like my project really wasn't that important. It felt like it was more of a “teach me program” rather than an actual “research program”. (I1)

Informally, Joseph had a number of science related hobbies. He collected radioactive objects and radiation detectors. One of his program counselors recounted an occasion where Joseph detected unsafe levels of Radon in the dormitory and brought his concern to her attention. Additionally, Joseph worked on experiments and built equipment in the backyard garage at his house in his spare time. In his own words, “I’ve been more of a freelance [researcher] where I [build] inventions and such... My inventions have ranged from an x-ray machine, which I built that was very fun, to things that... right now I’m [working on] a fusion reactor” (I1).

Joseph planned to attend a four-year university and major in nuclear engineering prior to attending the AESP. He also discussed wanting to continue in graduate school and get a Ph.D. in Nuclear fusion. At the end of the program, he still desired to major in nuclear engineering, but was considering other possible minors as a result of his laboratory experiences in the AESP. “I am still set on nuclear, but I’m looking at chemical [engineering] as a possible minor, or material science as a minor” (SI2).

As part of the program, Joseph enrolled in the reflective seminar. He was not paired with any other participant of the AESP in his research laboratory.

Laboratory description

Joseph worked in a materials engineering laboratory in the particle sciences building of the university during his apprenticeship. His laboratory was well secure and followed strict safety guidelines. All researchers and observers were required to wear laboratory safety glasses at all times when in the laboratory. Approximately half a dozen graduate student researchers worked in the laboratory. Many of these students were from South Korea and as such, Joseph encountered a great deal of ethnic diversity in his laboratory group. The PI of the laboratory, Dr. Wu, was a visible presence in the lab and was observed making rounds of his student's projects multiple times during the summer. George, a graduate student working with Dr. Wu, primarily mentored Joseph during the AESP.

Project description

The purpose of Joseph's research was to develop more uniform coatings of nanoparticles in order to increase the anti-reflectivity of certain materials. Such research held implications for the efficiency of solar panels. As will be discussed in future sections of Joseph's story, many of the ideas for his project were of his own development. The research paper that accompanied his project won the best paper award from the AESP.

Changes in NOS ideas

Over the course of the AESP, Joseph demonstrated positive changes in his understandings of the creative nature of scientific knowledge formation, the subjective nature of the generation of scientific knowledge and the myth of the scientific method as revealed through pre and post science surveys and corresponding interviews (Table 4-9). Table 5-7 contains representative excerpts from these data sources for Joseph that

illustrate his pre-experience views and his post-experience views related to each of the aforementioned NOS aspects.

Self reported changes in NOS ideas and corresponding influencing factors

Joseph was only able to self-identity changes related to his understandings of the myth of the scientific method. In doing so he often would talk about the “trial and error” that he experienced in the laboratory while conducting his research.

I didn't know that science was like the Wild Wild West. I mean I thought science was more about theory and such, but it seems like in our lab we're doing a heck of a lot more trial and error. If this doesn't work, try it. If this doesn't work, try it more. And that just impressed me. (I3)

He was genuinely “impressed” that in the work he was doing, he was much more free to explore as he saw fit. Joseph contrasted this with the way that scientific work is portrayed in science textbooks.

Basically, a scientific textbook really prepares you by saying, “If you're a scientist your job can be very monotonous.” Experiments are supposed to be like this, this and this with very little error too. Whereas in this program here, this is completely the opposite. Science is much more risky, and if there is error in your results that's fine and you should just... you can change things on the fly more if you know what I mean. You can change things very quickly. (I3)

In his laboratory, Joseph witnessed science that was conducted through a process of frequently modifying procedures. This was something that Joseph thought was not permissible in research science and he felt that his NOS ideas had changed accordingly.

I think they [my NOS views] did change, because I really didn't have this clear of a view as what science was per say, but again my view really was pretty limited too. I didn't know that scientists could be so impartial and I thought that they used a scientific method for virtually everything and that there were extended operating procedures. Where in our lab, we didn't have a standard set of operating procedures and our methods were very sloppy too. And I didn't think that was allowable in science, so that really changed my idea. (SI2)

Joseph stated that his ideas about the work that scientists had not changed, but just the way in which they “conduct it” (SI2).

Not only was Joseph able to self-identify the changes in his understandings of the myth of the scientific method, but his PI mentor, Dr. Wu, was also able to recognize that as a result of participating in the AESP, Joseph had come to learn more about how to conduct scientific research. Dr. Wu described this learning in the following ways.

So, for example, [Joseph learned] how to do independent research....He learned how to, once he has a project he learned how to start that, how to propose something new, how he can design the project or how he can design the steps to testing his hypothesis. (MI1)

You know, after seven weeks of doing the project, I believe he at least knows the beginning steps from the beginning of a project. How to identify the final goal and how to design the steps to achieve the final goal. That is very important. (MI1)

Joseph identified the laboratory placement as influencing his understandings of NOS. He said, “I guess the way that my mentors acted and how they really just worked and their extremely relaxed attitude [were the most influential factors]. (SI2).

Additionally, he said specifically that his laboratory placement was “the biggest factor” which impacted the way in which he thought about how science operates. As a member of the reflective seminar, Joseph completed a number of reflective journal prompts related to NOS ideas. However, he did not think that these influenced his perspectives in any way other than just getting him to think about them. He said, “It [the journal] made me think about my perspective in science, but it really didn’t teach me anything about science since it was just asking me questions about science” (SI2).

Authentic action

What Joseph was doing during his time in the laboratory was authentic in terms of what actually was common practice in the specific laboratory context where he was

placed, in this case an engineering laboratory. Joseph's authentic action can be conceptualized according to him proposing a novel idea, being involved in developing the ways to explore his new idea, collaborating with others as he did so and then eventually being involved in the sharing of his results.

In discussing the authentic action Joseph participated in during the AESP, Dr. Wu described the work that typically takes place in his lab.

What we usually do is we first propose a novel idea. A novel idea could be scientifically novel or technologically novel. We really as faculty we explore both... That is usually almost all of the students in my group, they need to do both. Not only using the trial and error way to figure out, to optimize conditions, that's usually what the industrial people are doing. But as a working academic field we need to understand why. We are not only asking how to achieve this, we need to know why. (M11)

Dr. Wu described the work in his laboratory as beginning with a novel idea. He continued in his mentor interview to discuss how Joseph's research came from a truly novel idea of Joseph's design.

Yeah, actually it [Joseph's research project] came out of a new idea, a brand new idea. I had never thought of that before, but it seems like a very important thing that we have missed before... The temperature. Lower temperature. Higher temperature. Seems like the temperature plays a very important role. So my graduate student [George] will continue his [Joseph's] work. I believe we will publish this work later on when we get enough data. (M11)

Joseph was able then to suggest a new idea, in this case lowering the temperature of the coating process he was investigating.

Additionally, Joseph himself recognized that more collaboration was involved during this investigative process than he was expecting. "Oh we collaborate a lot. I mean in our group right now if anyone in our group has a question about a process or such, you just ask anyone else and it's very interconnected... I wasn't expecting as much interconnectedness" (I1).

As was previously indicated, Dr. Wu recognized that Joseph's novel idea would be publishable in a peer-reviewed scientific journal. George, Joseph's graduate student mentor also described the work as being publishable and that Joseph would even be a co-author on the paper. "Our advisor has mentioned that more than likely he [Joseph] will be coauthored on a paper. So if that is not proof that he was a contributor, I don't know what is. (MI2).

Part of the reason that Joseph was given an opportunity to suggest a new idea in the first place was that Joseph's graduate student mentor, George, did not have an existing project to plug Joseph into.

So we have a process and we were trying to think of ways to improve it. So his [Joseph's] suggestion was to vary the temperature of the process, and try and go as... bring it down as low as possible to see the effect it would have on the crystal arrangements on the monolayer coated on a wafer... I was just kind of winging it. I didn't really have a plan or anything. (MI2)

In George's own words he was "winging it". This was very different from what the other case study participants experienced in their work with graduate students who were farther along in their studies and had the AESP participants work on data collection and analysis for the purposes of contributing to their respective dissertations.

Being treated authentically

A large part of the reason that Joseph was able to participate in authentic action appropriate for his laboratory group was that his mentors treated him in authentic ways during the apprenticeship. Joseph did not expect that he would experience the levels of acceptance that he encountered during his time in the laboratory.

I thought they wouldn't accept my ideas as much... But I'm surprised that my colleagues and my professor have been rather adaptive and extremely responsive to my ideas and such... I thought they [my ideas] would be reviewed and be reviewed and be reviewed until they were basically shot down. (I1)

Joseph thought that when he proposed a novel idea it would be dismissed. He discussed a specific occasion where he was able to try one of his ideas.

The other day I had the idea of actually coating on a coated wafer. So George said without hesitation, “just do it. Try it. See if it works or not.” There was no debating, no calculations; I said, “sure why not? I’ll see what happens”. (I3)

Joseph’s graduate student mentor George recognized that Joseph’s ability to propose research ideas was a particular strength of his. Once he recognized that, he gave Joseph the freedom he needed to explore his ideas accordingly. George described this during his mentor interview in the following ways.

Because Joseph is really good at coming up with ideas. That is one of his strengths. So if he had an idea, sometimes even if it was way out there, I would let him go after it just to see if there was something there. (M12)

I gave Joseph a lot of leeway to do what he wanted to do. But when there were things I needed him to do or wanted him to do, I had him do those things as well. So it was kind of back and forth I guess. Because Joseph had a very set plan that I think he had in his mind that he wanted to do... I gave Joseph a lot of slack to do what he wanted to do in the lab as long as I thought it was suitable. Because there were some things that I didn’t let him do either because I thought it was unsafe or we just didn’t have the resources to do it. So as long as I felt he was capable to do it, I let him do it. (M12)

Joseph additionally recognized that his mentors entrusted him with a great deal of responsibility to manage the laboratory in their absence. “I’m also given a lot more responsibility too. Like this morning I was the only person in my lab and I was able to run the whole lab too” (I3). On multiple occasions, Joseph was observed working independently on his project. It was clear to the observer that Joseph’s mentors trusted him to work authentically even when they were not there directing every step.

Finally, Joseph’s PI had an open-door policy with his students that applied to Joseph as well. In other words, when Joseph wanted to, he could discuss his project

with Dr. Wu and Dr. Wu treated him just as he would any other student. Dr. Wu described this policy during his mentor interview.

My policy, my group's policy is when they see my door open, they can come in here. It's an open door policy. Although sometimes I am hiding here writing papers, writing proposals, but that's not often. So usually I would meet with Joseph almost every day. (M1)

Feelings of authenticity

Joseph felt like he was an authentic contributor within his laboratory group. He felt this very early on in the AESP. During his first interview, he said, "I feel like a contributor, obviously... a person of the group" (I1). Not only did he feel like part of the group, he felt like an "important part of the group". He attributed this to the "good ideas" that he had proposed.

It feels like I am a very important part [of my research group]... A person of that team actually said that they were surprised with how quickly I caught on with the material and that I'm doing a very good job too and many people in the chemical engineering department thought that I was like a graduate student there because I had a few good ideas. (I1)

Joseph continued in this first interview to describe that he was making a contribution to his field that even went beyond the walls of his specific laboratory.

It feels like I can actually relate with these people in the lab and it seems like even though I'm new to the actual field... it seems like a lot of my theories and such are actually very credible and such, and it seems like I'm actually contributing to the collective science as well. (I1)

In his second interview, his feelings of belonging to the laboratory shifted to being related to the pride that he felt based on the successful results he was obtaining. "Basically, when there was a visual confirmation that my hypothesis was correct, George said good job and that was just confirmation that I've actually made a mark on this lab" (I2).

By the time of the third interview, Joseph described himself as a scientist and thought that the AESP had led to him becoming an even “better scientist”. He said, “This program has really allowed me to become a better scientist in general, if I can call myself that more” (I3). He thought that he would not experience the degree of equality that he ended up feeling that he had obtained through his participation in the authentic action of the laboratory group. “I thought I would be just another glorified research assistant, but I’m actually doing stuff here and like an equal almost. Yeah, an equal” (I3).

Joseph’s mentors recognized that he saw himself as an authentic member of the laboratory group. Part of this was seen through Joseph’s enthusiasm and interest in his project. George described this during his mentor interview.

I think he [Joseph] sees himself as a contributor. Like he really wanted to do work. He asked me if it was possible if he could do work back home and communicate with us what he was doing, or if he could come back next summer. So he really is enthusiastic about what he is doing and what he is contributing. (M12)

Joseph described his interest in the project as being related to the discoveries that he had made and the encouragement that he had received from his mentors as a result.

[I’m] probably a bit more [interested] since I’m getting more into the meat and the bones now and it seems like it’s getting more intriguing and such. Like the other day I made a natural discovery, which proves my theory was correct at some point. (I2)

Just to see the actual impact that I could have by doing chemical engineering [increased my interest in the project]... And the fact that I can just contribute to processes as well, in addition to positive encouragement from the grad students and my PI as well. (I3)

Finally, Joseph felt that his project produced results that were genuinely valuable to his research group and that this value was evidenced by the fact that his work was publishable. He said, “My actual mentors were extremely impressed with my results and

my PI is actually going to publish my results too, which he obviously wouldn't do if they weren't valued" (13).

Summary

Joseph entered the program with the most extensive background in science of any of the six case study participants. He was also the most willing to participate in actively in the work of his laboratory group. As a result, perhaps Joseph would have had a similarly positive experience where he received supporting implicit NOS messages regardless of the particular laboratory in which he was placed. Joseph's mentors were able to recognize this skill set and gave him freedom to contribute epistemically to the development of his project. His mentors allowed him to perform whatever procedural tasks he desired as he explored hypotheses of his own design. Joseph's graduate student mentor, George, was a beginning graduate student and was not yet working on his dissertation project. Therefore, Joseph was able to contribute novel ideas to his project as he was not just plugged into working on a very specific and already existing research project. Joseph felt that the procedures he was implementing were not set in stone and he felt free to experiment with "trial and error" methodologies. This high level of authentic action carried implicit messages that in this case positively impacted Joseph's understandings of NOS. These implicit messages carried through authentic action held even greater weight for Joseph because he was treated authentically and as a result developed feelings of authenticity as he felt like a contributing member of the laboratory group. Based on the science survey and corresponding interview data supported by both participant and mentor self-identified NOS changes during semi-structured interviews, it is likely that Joseph's understandings of the myth of the

scientific method were most positively impacted during the AESP as a result of the implicit messages he encountered in his laboratory placement.

Constructed Theory

The end product of constructivist grounded theory is an overarching theory explaining the phenomenon under investigation (Charmaz, 2006). In this case, the theory emerged from all data sources and was co-constructed by the researcher and the participants in the study. For the purposes of this report, the emergent theory will be explained in two different figures.

Figure 5-2 accounts for the sources of all possible changes in NOS ideas for all thirty of the research study participants. This figure provides a macro-level perspective of the entire AESP. Included in the figure is the participant learner, the explicit/reflective seminar, the program itself, the PI mentor, graduate student mentor, the laboratory environment and the research project; most of which carried explicit and/or implicit messages which may have positively or negatively impacted participant's NOS ideas. Only the explicit/reflective seminar is included in this figure as categorical data analysis revealed that this was the only seminar where participants as a whole experienced significant and positive change regarding their NOS views. The program itself carried explicit messages regarding certain NOS aspects to the students. This was evident in the case of Tom who recognized that a hypothesis was a requirement of the program to be included in his research paper and presentation (Table 5-4). The rest of the case study participants all had the same requirement that may have carried an explicit message regarding the myth of the scientific method. The mentors themselves could have provided explicit messages that impacted the case study participants' understandings of NOS. This was evident in the case of John who came to better

appreciate the tentativeness of scientific knowledge through explicit conversations he had with Rebecca, his graduate student mentor. In observing the way in which the PI mentors and graduate student mentors conducted scientific research, the participants may also have received implicit messages regarding NOS. Similarly the laboratory environment and the nature of the project itself had the potential to carry implicit NOS messages. The participant is represented prominently in this figure because the implicit messages carried through the laboratory were a function of the participant's involvement in the authentic action that was taking place therein. The participant must have taken an active role within the laboratory group in order for them to construct meanings of the NOS ideas related to the activity of that group.

Figure 5-3 accounts for the implicit messages that the six case study participants may have received in their laboratory environments and that may have impacted their NOS understandings. Participant engagement in authentic action was the primary avenue for conveying implicit messages about NOS in their laboratory placements. Related to this authentic action were both characteristics of the participants and the ways in which participants were treated by their mentors. Participant characteristics such as their willingness to participate, the development of feelings of a scientist identity and the personal background of the participant were related to both the action that the participant was involved in and the quality of the mentorship that they received. The relationship between authentic action and characteristics of the participant is represented in Figure 5-3 by a double arrow, because the authentic action of the participants influenced the way that they thought of themselves within the community of scientific practice, and simultaneously their feelings of authenticity influenced how they

personally conceptualized the meaningfulness of that authentic action. Participant characteristics and treatment by mentors are also related to each other in the figure by a double arrow. When a participant was treated in a positive way, as was the case with Joseph, they developed feelings of authenticity. Simultaneously, the personal characteristics of the participant determined how mentors interacted with him or her.

Conclusion

In summary, all six case study participants experienced growth in some aspects of NOS. These changes in NOS ideas were likely a result of complex combinations of both explicit and implicit messages received during the research apprenticeship. Explicitly, students that participated in the explicit/reflective seminar and/or had mentors that engaged them in explicit NOS conversations experienced growth in their understandings of certain NOS aspects. However, some case study participants that experienced limited explicit NOS messages also exhibited positive changes in their NOS understandings. Such growth can be attributed to implicit messages participants received in their laboratory placements as they authentically and actively participated in scientific research accompanied by the development of a scientist self-identity as those who were mentoring them treated participants like authentic members of their laboratory groups.

Table 5-1. Case study data source abbreviations.

Data Source	Data Source Abbreviation
Written Science Survey (Pre-Experience)	S1
Written Science Survey (Post-Experience)	S2
Science Survey Interview (Pre-Experience)	SI1
Science Survey Interview (Post-Experience)	SI2
Semi-Structured Interview 1	I1
Semi-Structured Interview 2	I2
Semi-Structured Interview 3	I3
Observation 1	O1
Observation 2	O2
Observation 3	O3
Observation 4	O4
Observation 5	O5
Observation 6	O6
PI Mentor Interview	MI1
Graduate Student Mentor Interview	MI2

Table 5-2. Representative data of positive NOS change: Jane

Aspect	Pre-Experience	Post-Experience
Empirical	On the causes of dinosaur extinction: "it is history that we cannot go back and see." (S1)	"There can be different interpretations of information." (S2)
Theory/Law	"Theories are something that scientists believe to be true because they haven't been proven false yet. Laws are known to be true because they've been proven." (S1)	"A theory will describe...it's kind of a description of something, but a law tries to explain like why something happens." (S12)
Creative	"I don't believe they [scientists] use their imaginations because science must be objective." (S1)	"They [scientists] may use creativity when modifying methods or procedures to correct their experiment. This happened in my lab when the first method didn't work out correctly." (S2)
Subjective	"Science is objective. While art, history, etc. is subjective. In science, there is always a right or wrong answer." (S1)	"A lot of it [subjectivity] is in their [scientists] own personal background, that like comes into play when you're analyzing data." (S12)
Social-Embeddedness	"I think that science is universal." (S1)	"Science does reflect social and cultural values... in more conservative cultures, women don't perform scientific experiments." (S2)
Tentative	"Science is the same everywhere." (S11)	"It [scientific knowledge] changes with time... We used to think the world was flat and now we know its round. As you get more information, your beliefs about things change." (S12)
Myth of the Scientific Method	"Not only do you have to prove that what you're saying is right, but you also have to prove that what is already believed is wrong and that there is no way it can be true." (S1)	"Most scientist do [follow the scientific method] but some are not able to due to the nature of their research." (S2)
	"All scientists should use the scientific method if they want their research to be seen as credible. It is universal and ensures a correct procedure and results when carrying out an experiment." (S1)	"Well a good example was in my lab... we didn't really have a hypothesis, we were just kind of trying to figure out how to get the conclusion that previous research had come to [in a different way]. So I mean, we couldn't follow the set rules." (S12)

Table 5-3. Representative data of positive NOS change: Isabel

Aspect	Pre-Experience	Post-Experience
Creative	"I think that when a scientist is planning and developing a hypothesis is when they use their imagination." (S1)	"They [scientists] most definitely use it [creativity/imagination] when they are interpreting their results because they have to think of all the reasons why the results came out that way. Meaning, sometimes they have to think the impossible or least possible thing could have happened." (S2)
Subjective	"You [as a scientist] have to follow the theories that scientists in the past had set up, so your mind can't just go all wild." (S1)	"It [varying perspectives] is [a result of] the way you [a scientist] interpret it... They [scientists] all have the same results but they might have a different explanation on why they got the results." (S2)
Tentative	<p>"Well it [change in scientific knowledge] depends. Because there are some theories that are still being tests out and they're not fact, because they don't really know the specific detail. They can't really prove it that well, so as technology improves, it's something that is proved stronger." (S1)</p> <p>"Yes it [scientific knowledge] may change in the future because of the advanced technology that always seems to be improving. For example, we don't think that we can ever land on Pluto, but one day, technology will help prove that wrong." (S1)</p>	<p>"Our knowledge of certain things is always changing... for example, our knowledge of the planet Pluto. It is no longer considered a planet because the definition of a planet has changed." (S2)</p> <p>"Well, we're always gaining new knowledge from it. We're always answering a whole bunch of new question and constructing...we're also finding out new things that we never even knew about... like how Pluto was once thought a planet and now it's no longer considered a planet because of what they [scientists] redefined [as] being a planet." (S2)</p>

Table 5-4. Representative data of positive NOS change: Tom

Aspect	Pre-Experience	Post-Experience
Empirical	On the differences between theories regarding dinosaur extinction: "They [scientists] disagree because of inaccuracy when dealing with such old things." (S1)	"When you get to the atomic level, it is more of the outward reaction of it that you can see that kind of gives you an idea of what is really there." (SI2)
Myth of the Scientific Method	"I'm experiencing a lot of lab right now where we are really not [using the scientific method]... For instance, what I'm working on this summer, I am just observing the effect of pH on this protein. I'm not actually asking the question. I'm not trying out to prove anything... So yeah, everybody doesn't follow the exact same method. You don't need a hypothesis. Like I don't have to say a lower pH will blah, blah, blah. It's just observing the fact. So in elementary [school], yes, they kind of made you follow those guidelines. But as you move on I guess, it's not as structured." (SI1)	"I mean I could have left off the hypothesis. That was sort of thrown in there, because it was a requirement on the paper. I remember asking Lisa [about a] hypothesis. She was like 'What? Who makes a hypothesis these days? Are we in middle school?' I mean, I don't know. It's a cool thing to have, but I can definitely tell that like, not necessarily in the biochemistry or chemistry lab. They don't really like make a hypothesis when they do the project. I mean they're just like mixing chemicals and things and... it's sort of observing what's going to happen. Which I would say is mostly like our project. Like Lisa stressed that. She was like, 'There's not really necessarily a prediction or a more efficient thing that you're trying to look for. You're just sort of observing what the results are.' The hypothesis thing was really more of a creation for the research paper... but I would say for the most part scientists don't hypothesize." (SI2)

Table 5-5. Representative data of positive NOS change: Jennifer

Aspect	Pre-Experience	Post-Experience
Empirical	On convincing others of a theory of dinosaur extinction: "First they [scientists] would have to prove how other theories are incorrect and then present their theory and prove how it is correct." (S1)	On convincing others of a theory of dinosaur extinction: "They need to get a lot of evidence supporting their theory and need to disprove all other theories." (S2)
Subjective	On disagreements over what caused dinosaur extinction: "this is just a matter of belief and I don't think they will ever agree because they were not there when it happened so they will all have different theories." (S1)	On disagreements over what caused dinosaur extinction: "They disagree because they are different people with different minds so they look at information and each come up with their own explanations for the information." (S2)
Tentative	"Science, unlike art, history, philosophy, and other similar subjects, has a set answer for everything." (S1)	"Scientific knowledge is always changing and will change in the future. Right now we may think that something is a certain way because of a reason, but in the future, we might know that to be true but for a different reason." (S2)
Myth of the Scientific Method	"It [the scientific method] is something that you try to follow, especially when they teach you what the method is...you might have to start with something else and it may not lead you into the method in the order that they originally tell you, but it is going to go over a general path at the end." (S11)	"There are like some studies where all you do is like observe people and then there are some studies when you just experiment on things." (S12) "Even this generic approach [the scientific method] like can be changed into another generic approach." (S12)

Table 5-6. Representative data of positive NOS change: John

Aspect	Pre-Experience	Post-Experience
Empirical	<p>"If you're trying to prove and telling other scientists, a scientist isn't going to believe your word, he's going to need proof, documents, you know articles. Like pretty much stuff ... he doesn't want something you assume or an argument or something everyone has been talking about. As a scientist you want something you have done, data, why do you think this happened... From what I know a lot of scientists can be stubborn, they only believe what they believe in, they're very stubborn. They do an experiment because they want to find out what they think they already know. So if somebody else is trying to contradict what you're saying, you need really good proof to make scientist believe that you're saying the right stuff." (S11)</p>	<p>"Scientists won't believe something you tell them, they have their own belief and unless you can show them accurate support. That's the only way the believe things...enough that the results are accurate. Like for example, if I showed my results to a scientist, I don't think they would believe me just for the fact that my sample size wasn't big enough. Like they wouldn't take P values of 0.072, they would want more accurate results." (S12)</p>
Creative	<p>"They [scientists] may use it [creativity/imagination] in their hypothesis, but scientists understand that experiments are all about facts." (S1)</p>	<p>"Creativity was in the way we showed our results. The kind of graph we used." (S12)</p>
Social-Embeddedness	<p>"Science is universal." (S1)</p>	<p>"I also think it [science] reflects social and cultural values because for example many people believe in evolution and some don't, and this affects the way of thinking and creates different theories about the world...[and] they [scientists] would have different studies [as a result]." (S12)</p>
Tentative	<p>"If they [scientists] weren't certain about it [the structure of an atom] then they wouldn't be teaching it in school." (S11)</p>	<p>"They [scientists] just don't ever prove anything. They just have results and they're also never 100% sure, it could be 99 percent sure... she [Rebecca] said that scientists don't ever prove, because like when I was going over my presentation I said, 'So we proved that you know this and that.' And she said, 'Don't say prove, because scientists don't ever actually prove anything.' So that was something I learned here." (S12)</p>

Table 5-7. Representative data of positive NOS change: Joseph

Aspect	Pre-Experience	Post-Experience
Creative	"[Scientists use creativity] mostly in the theoretical stages in the designing of the experiment and choosing your dependent and independent variable along with your hypothesis." (S1)	"Scientists use creativity/imagination when: "Planning: How to record data and carry out the experiment. Observation: How to make lower bias observations. Reporting results: How to report results in the most efficient manner possible. For example, when I conducted my cold experiments, I needed to think about what variables I had to manipulate and to what extent...I'll give you an example. When we coated with our 100 nanometer particles and we didn't see results at a warmer temperature, I could have just thrown in the towel, but I decided to change variables. One time, I decided to coat at a lower temperature by chilling an entire beaker full of water." (S12)
Subjective	"Good scientists [make] unbiased predictions." (S1)	"But someone might interpret that data differently given the societal constraints... Suppose we lived in maybe Darwin's time or so. They [scientists] might have looked at this data and shrugged upon it... even today, some cultures in some societies disregard his work, whereas like in our society... [scientists] believe in this work and they do not believe in the work of like Lamarck's theory of use and disuse." (S12)
Myth of the Scientific Method	<p>"The scientific method is a series of steps that a hypothesis has to go through in order to become a valid part of the scientific community." (S1)</p> <p>"All scientists must use the scientific method because it is the unifying steps of procedure that help validate a scientific model." (S1)</p>	"No, [we didn't use the scientific method], because we just used a trial and error method... it wasn't conventional... it was just a quick and dirty trend that we saw... trial and error and experiment after experiment and just seeing what happened." (S12)

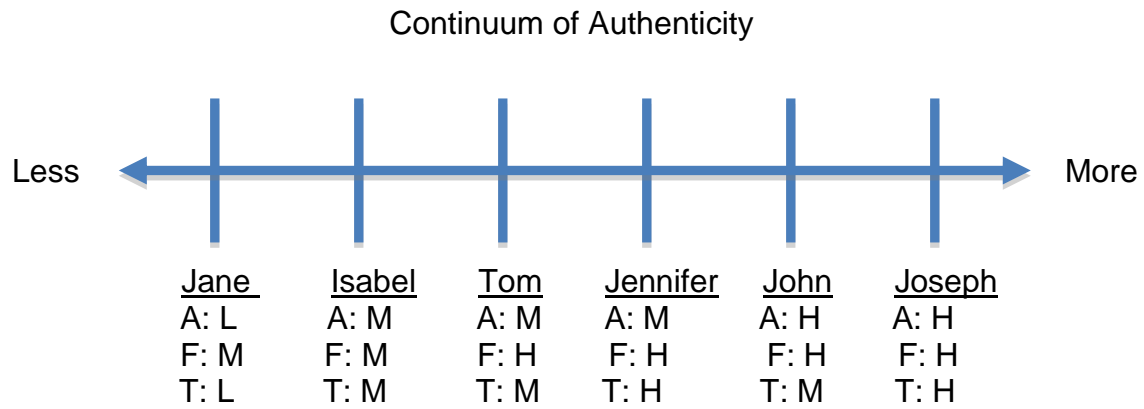


Figure 5-1. Continuum of authenticity for case study participants in terms of action (A), Feelings (F) and Treatment (T).

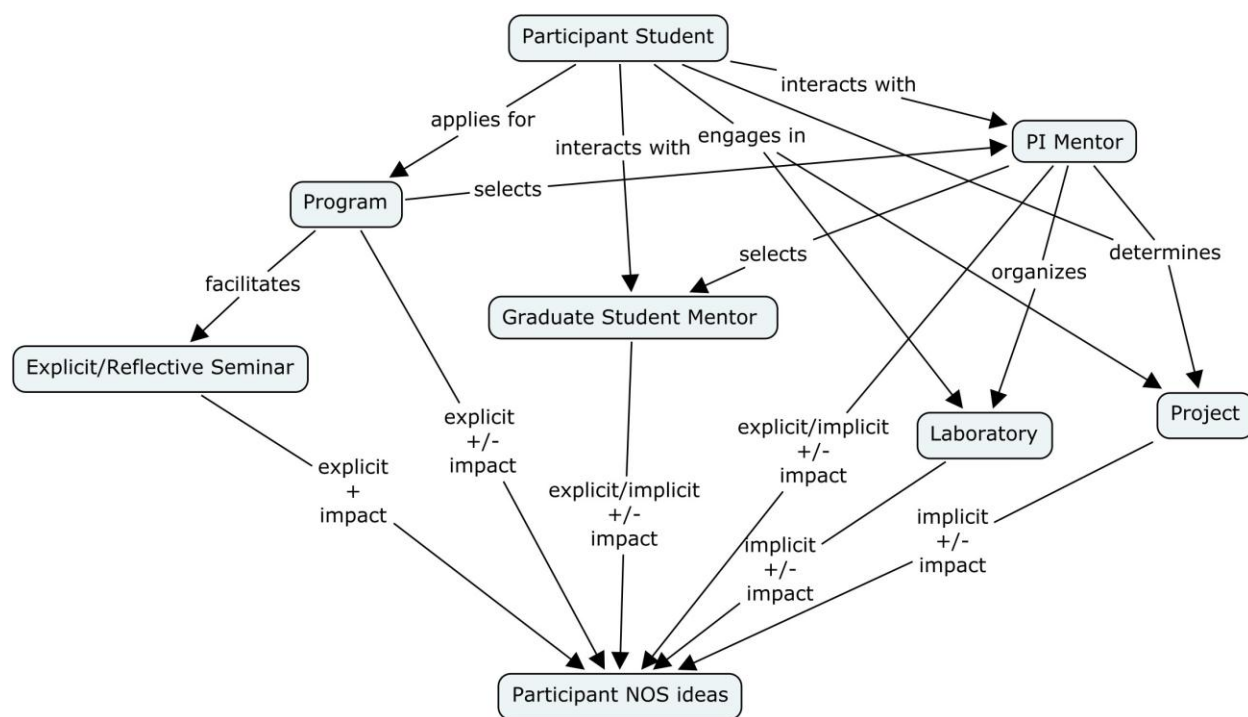


Figure 5-2. Impacts from explicit and implicit messages on participant NOS ideas in the context of the AESP.

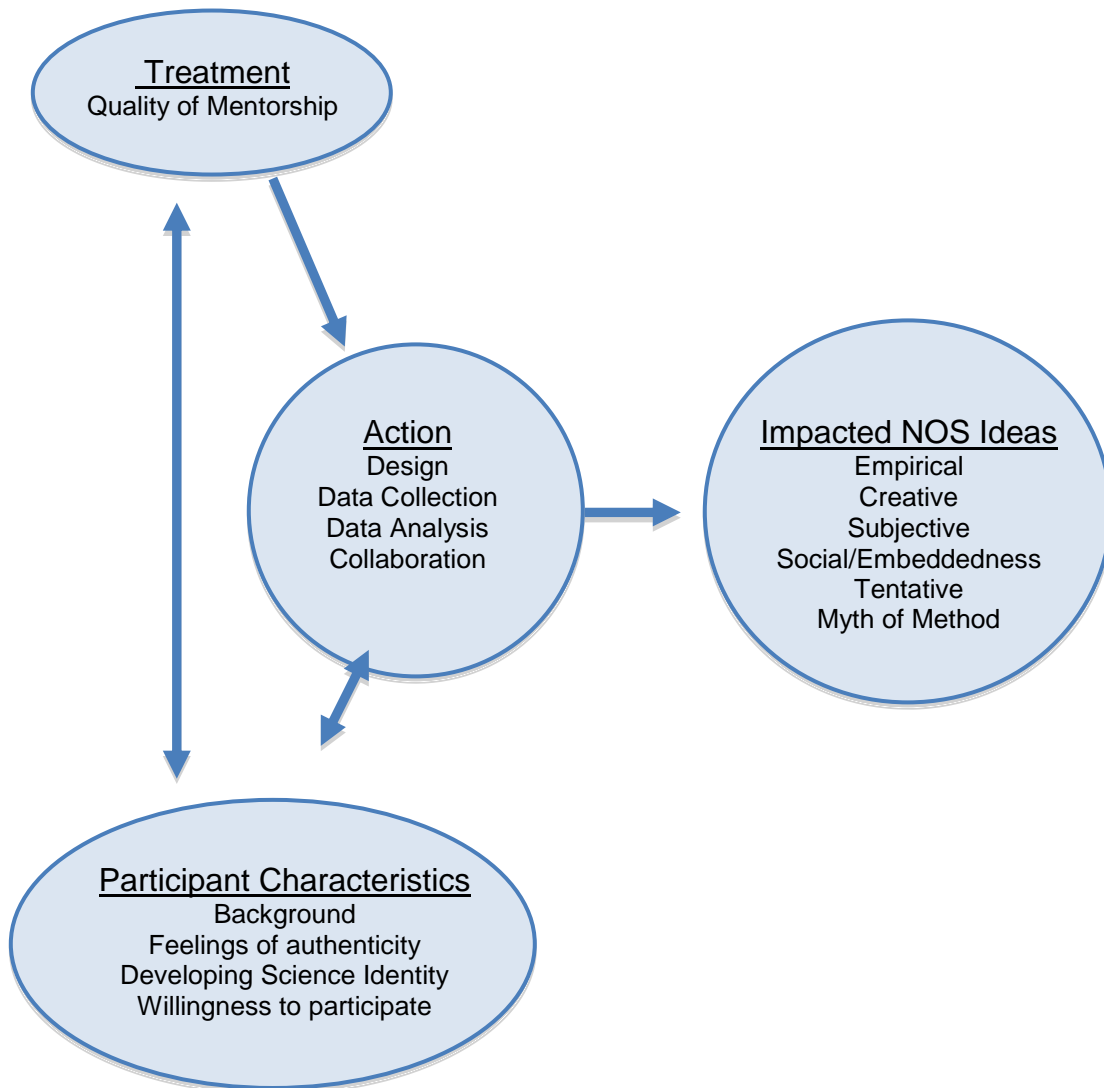


Figure 5-3. Relationships between authentic treatment, participant characteristics, action and impacts from implicit messages on participant NOS ideas in the context of the AESP.

CHAPTER 6 DISCUSSION

Overview of Study

The present study investigated the impact of involvement in authentic scientific research experiences like research apprenticeships on participant conceptions of NOS. Historic reform documents in science education have emphasized the participation in and understanding of scientific inquiry as well as the understanding of NOS as important components of scientific literacy (AAAS, 1993; NRC, 1996). However, more recent frameworks in science education, which will guide the development of a new generation of science standards, contain less explicit references to NOS and have replaced the notion of inquiry with that of science and engineering practices (NRC, 2007; 2012). It is argued in the new framework that, “these practices should reflect those of professional scientists and engineers” and that “engaging in the practices of science helps students understand how scientific knowledge develops” (NRC, 2012, p. 42). Even more specifically, the authors of the framework suggest that the “actual doing of science” will “help [students] recognize that the work of scientists and engineers is a creative endeavor” (NRC, 2012, p. 42-43). In other words, when students participate in the practices of professional science, it is believed that they will better appreciate certain aspects of NOS including that knowledge production in science is a result of creativity on the part of scientists. Thus in the new framework, scientific inquiry and NOS overlap in significant ways.

The teaching and learning of NOS has traditionally taken one of two approaches: either an explicit/reflective or an implicit approach. The author of a recent review of empirical research related to NOS concluded that, “conceptions of NOS are best

learned through explicit, reflective instruction as opposed to implicitly through experiences with simply ‘doing’ science” (Lederman, 2007, p. 869). Such a position challenges the argument made in the new framework document that engaging students in the practices of science would be an effective strategy to positively impact their NOS understandings. These two contrasting positions regarding the teaching and learning of NOS are highly dependent on the context in which science learning takes place. In school science where the typical laboratory activity is often very dissimilar from the actual practices of working science (Chinn & Malhotra, 2002; Hofstein and Lunetta, 2004), it is not surprising that an implicit approach is not particularly influential. However, in canonically authentic contexts (Buxton, 2006) where students participate in practices closely resembling those of professional scientists as advocated in the new framework (NRC, 2012), it may be that implicit messages related to NOS can be quite powerful in impacting student NOS perceptions. Sandoval (2005) argues that students hold very different practical epistemologies of science related to their own work in science compared to their conceptions of the formal epistemologies driving the work of professional scientists. Engaging students in research experiences in professional science laboratories through research apprenticeships might increase the impact of the implicit messages carried through such participation on student NOS understandings as their formal and practical epistemologies of science may overlap. Recent research suggests that in the specific context of the investigated research apprenticeship in science, formal and practical epistemologies held by participants are to a certain degree consistent with each other (Burgin & Sadler, 2012).

In this present study, a summer residential research apprenticeship program for high school science students served as the context for investigating the issues discussed above. The study was guided by two research questions. The first research question directed an exploration of the impact of three different approaches (explicit/reflective, reflective and implicit) to NOS teaching and learning implemented during the authentic research experience on participant conceptions of NOS. Through an investigation of the second research question, influential characteristics of laboratory placements that may have implicitly and/or explicitly carried messages which impacted participant NOS ideas were identified and linked to specific NOS aspects.

In the sections that follow, a discussion of the research findings is presented. First, the main findings as they relate to the two research questions are discussed. The chapter continues with a discussion of the implications of this research and subsequent recommendations for stakeholders of authentic science research experiences outside of school and for stakeholders of traditional school science settings. The chapter concludes with a discussion of the limitations of the research and concludes with suggestions for future research investigations.

Discussion of Main Findings

Approaches to NOS Teaching and Learning

Seminars offered in conjunction with the Authentic Experiences in Science Program (AESP) allowed for a comparison of three different approaches to NOS teaching and learning in the context of a research apprenticeship. The three approaches investigated were an explicit/reflective, a reflective and an implicit approach. A modified version of the VNOS questionnaire (Lederman et al., 2002) the ISS was administered to participants experiencing each of the three approaches both at

the beginning and again at the end of the AESP (Appendix B). Categorical data analysis of this instrument revealed the strength of the explicit/reflective approach over the other two approaches regarding impacts on participant NOS views. Specifically, understandings of the distinctions between theories and laws as different forms of scientific knowledge and the myth of the scientific method were impacted positively in a statistically significant way ($p < 0.05$) for the participants of the explicit/reflective seminar collectively. Additionally, participants of the explicit/reflective seminar, as a whole, displayed positive changes in their understandings of the social-embeddedness of scientific knowledge that while not statistically significant did reveal a meaningful trend ($p = 0.0588$). No such significant whole group changes in any aspects of NOS were noted for either the reflective or the implicit approaches implemented in the other two investigated seminars.

The NOS changes exhibited by the members of the reflective seminar were not significantly different from those exhibited by the members of the implicit seminar. Based on these findings, the approach utilized in the reflective seminar was revealed to have impacted NOS understandings no more than the approach utilized in the implicit seminar did.

The quantitative findings of this study are consistent with a large portion of empirical literature in science education. For example, the findings are compatible with the results of other studies that have compared explicit/reflective and implicit NOS approaches in a systematic way that empirically demonstrated the merits of an explicit/reflective approach in a school science context (Khishfe & Abd-El-Khalick, 2002; Yacoubian & BouJaoude, 2010). No similar studies have compared various NOS

approaches in a context outside of a traditional school setting that would have been more representative of the AESP. However, independently the implementation of an explicit/reflective approach within authentic science research experiences has successfully influenced both secondary learners' and preservice teachers' views on a wide variety of NOS aspects (Charney et al., 2007; Schwartz et al., 2004). Additionally, a number of studies have demonstrated the weakness of implicit approaches in how they impact learner NOS conceptions in both school science settings (e.g. Moss, 2001; Sandoval & Morrison, 2003; Wu & Wu, 2010) and in authentic science contexts (e.g. Aydeniz et al., 2010; Bell et al., 2003; Hsu et al., 2010; Ryder et al., 1999).

Although no whole-group statistically significant changes in NOS understandings for the participants of the reflective and the implicit seminars occurred, there were a number of students in both groups who demonstrated both positive and negative changes in their understandings of certain NOS aspects (Table 4-4). Such findings speak to the potential of implicit approaches (i.e. the doing of science) to impact learner understandings of NOS. In this study, the aspects of NOS that were most often positively influenced for the participants of the reflective and implicit seminars were the empirical, creative, and tentative nature of scientific knowledge as well as the myth of the scientific method. Case study participants from the reflective and implicit seminars who demonstrated growth in their understanding of the myth of the scientific method (e.g. Joseph) happened to be placed in laboratories where the research being performed did not adhere to a strict application of the scientific method. The only NOS aspect that no participants of either the reflective or the implicit seminar understood in a more sophisticated way at the end of the AESP was the theory/law distinction.

Other literature in science education reports similar impacts from an implicit and/or reflective approach on secondary and undergraduate student NOS conceptions in the context of authentic scientific research both in and out of school. For example, one study has demonstrated that student participation in open-ended inquiry experiences that share key features of authentic scientific practice has the potential to influence secondary students' perceptions of the tentativeness of scientific knowledge even in traditional school science settings (Yerrick, 2000). Several empirical studies investigating implicit NOS approaches in the context of authentic science research experiences have documented gains in participant NOS conceptions primarily related to the construction of scientific knowledge (i.e. that science is subjective, socially embedded, etc.) and that scientific knowledge varies in certainty (e.g. Barab & Hay, 2001; Bleicher, 1996; Burgin et al., 2011; Ritchie & Rigano, 1996; Richmond & Kurth, 1999). In one research experience for undergraduate students that took an implicit approach to NOS teaching and learning, students were observed to develop more sophisticated understandings of the myth of the scientific method (Sabatini, 1997). Additionally, participants in another research experience for undergraduate students came to appreciate that science is rarely conducted alone (Cartrette & Melroe-Lehrman, 2011). It could be argued that implicit messages related to the subjectivity of science could come across more clearly as a group of scientists work together to negotiate a shared interpretation of data. Tom, a case study participant in the present study, similarly developed more sophisticated understandings of the subjective NOS during his time in the AESP as he collaborated with others when conducting his research.

Collectively for the participants of all three intervention seminars, the NOS aspect with the lowest instances of positive growth and the most instances of negative change was the idea that scientific knowledge is constructed rather than discovered. Perhaps the reason that participant understandings of this aspect were so resistant to positive change was that the survey question used to assess this topic asked students whether they believed that scientific knowledge was constructed or if they believed that it was discovered. Such a question examined participants' ontological assumptions about the nature of reality and truth rather than their epistemological understandings of how knowledge is generated in science. The level of philosophical abstraction assumed in the question may not have been appropriate to use in order to gauge the levels of sophistication of high school students' conceptions of this NOS aspect.

It is clear then that impacts from an implicit approach on certain NOS understandings are possible when students participate in authentic scientific research experiences. But what exactly influences these understandings? What implicit messages do learners receive when they participate in the practices of authentic science? What explicit messages do learners receive from their mentors in specific laboratory contexts? The six case study participants that were interviewed and observed in their laboratory placements exhibited growth in some of their NOS understandings. The analysis of these data sources shed light on some of the reasons for this growth. Attention is now turned to the implicit and the explicit messages received by the six case study participants during the AESP.

Implicit and Explicit NOS Messages

The participants in the current study encountered both implicit and explicit NOS messages coming from many different sources during the AESP. At times, as was the

case with Jennifer, these implicit and explicit messages positively reinforced each other. Jennifer was a member of the explicit/reflective seminar where she received explicit NOS messages through purposely designed activities and discussions. She also spent time in a laboratory environment where she received implicit messages through the authentic action in which she participated. For Jennifer, these implicit messages were related to the development of her understandings of the subjective nature of scientific knowledge and the myth of the scientific method. However, Jane, also a member of the explicit/reflective seminar, experienced the same explicit NOS messages as Jennifer outside of the laboratory, but encountered implicit NOS messages in her laboratory placement that seemed to work against the target NOS ideas. Jane did not participate in high levels of authentic action in her laboratory and the science-in-practice that she observed was performed in a very isolated rather than collaborative way. However, the explicit messages Jane received in the seminar were observed to overpower any negative implicit messages she may have picked up in her laboratory placement because many of her NOS ideas were positively impacted during the AESP. Therefore, Jane's seminar experience was more influential in impacting her NOS ideas than was her laboratory experience.

Other case study participants received explicit NOS messages during the AESP from sources other than the explicit/reflective seminar. For example, Tom described how the program itself required his paper to be set up in a way that was aligned with the traditional scientific method. He then had a discussion with his graduate student mentor about how parts of the scientific method, namely the hypothesis, were not required and often not used in research chemistry. In this case, Tom received explicit messages

about the myth of the scientific method from both the program itself and from his mentor that were at odds with each other (Table 5-4). John was another participant who received explicit NOS messages from his graduate student mentor. John had conversations with his mentor that explicitly focused on the uncertainty of scientific knowledge and the idea that scientists can never “prove” anything. Both Tom and John were members of the implicit seminar that collectively experienced no significant growth in NOS understandings. In research exploring the effects of authentic research experiences on NOS ideas, Bell and colleagues (2003) found no substantial impact of a program using an implicit approach to NOS teaching. However, one student who, like Tom and John, engaged in explicit NOS conversations with her mentor, demonstrated gains in her understandings of certain NOS aspects. This student developed more sophisticated understandings of the creativity involved in science when accounting for multiple interpretations from the same set of data (Bell et al., 2003).

Other case study participants (i.e. Isabel and Joseph) experienced very few explicit NOS messages during the AESP. For them, changes in NOS understandings were attributed to the implicit messages that they received primarily from their laboratory placements. In the case of Joseph, the implicit messages that he received were powerful and influenced his ideas regarding the creative nature of science, the subjective nature of science and the myth of the scientific method. For him, these implicit NOS messages were powerful in that they accompanied authentic action, authentic treatment and the subsequent development of feelings of authenticity as Joseph’s science identity was impacted as a result of his participation in scientific

research. Authenticity as an avenue for implicit NOS messages will be discussed in the following section.

Authenticity in Research Science

Drawing on the framework described by Buxton (2006), the AESP was recognized to be representative of a highly canonically authentic context for the practice of scientific research. In canonical authenticity, the key features of authenticity are determined not by the learners themselves, but by an external entity, in this case professional science. The AESP was not designed to allow participants to construct their own meaning of what it means to practice science, but rather to immerse them in action that mirrored the actual practices of professional science in order to introduce them to the established features of that community. According to this framework, the degree to which the AESP was authentic for an individual participant was directly related to how closely their experience in their specific laboratory context reflected the actual experiences of the working members of that laboratory. These laboratory group members were typically graduate student researchers.

The researcher embedded himself in the laboratory contexts of six case study participants of the AESP in order to understand the workings of each context and how the messages received by the participants therein may have influenced their NOS perceptions. Through an analysis of a variety of data sources (Table 3-5) a clear picture emerged regarding the levels of authenticity experienced by each of these participants and how that authenticity was related to implicit NOS messages that may have influenced their NOS ideas. An application of constructivist grounded theory techniques guided the analysis process (Charmaz, 2006). Three theoretical themes that were grounded in the data were generated through this analysis and were used to categorize

the authenticity experienced by each case study participant in their respective laboratory placements. These themes were the action, the treatment and the feelings that were both observed and self-described by the case study participants and their mentors. Figure 5-3 provides a visual representation of how these three themes interacted with each other to influence participant NOS ideas. Each theme will now be discussed in turn.

Action

Situated learning theory suggests that learning takes place as learners participate legitimately in the actions of a group sharing a specific cultural identity (Lave & Wenger, 1991). For each case study participant, that group consisted primarily of graduate student members within a research science laboratory team. The authenticity of the action taken by the case study participant was classified according to how legitimately it represented the normal practices of the graduate student assigned to work with the participant. These normal practices included but were not limited to the development of research questions, the design of investigative procedures, the collection and interpretation of data, the construction of conclusions and the reporting of those findings through a variety of means including research papers and presentations. An additional aspect of the action occurring in these canonically authentic contexts was the collaboration between graduate students and PI of the laboratory.

Learner participation in the development of research questions and in the design of investigative procedures can be described as epistemic involvement. In this study, only two case study participants (John and Joseph) were involved to any degree in the design of their respective studies. Neither participant was a member of the explicit/reflective seminar and both experienced growth in their understandings of

certain NOS aspects. One NOS aspect that both John and Joseph came to better appreciate was the idea that the construction of scientific knowledge is a creative process. Perhaps engaging participants epistemically in the design of a scientific research investigation carries with it implicit positive messages regarding the creative NOS. Although one previous study did not link epistemic involvement to desired outcomes of research apprenticeship experiences (Burgin et al., 2011), other research has placed an importance on this type of action in the context of an authentic research experience in science particularly as it relates to the development of scientific reasoning (e.g. Hay & Barab, 2011; Ryder & Leach, 1999). Bell and colleagues (2003) similarly found “epistemic demand” placed on the learner by the mentor scientist in a research apprenticeship to be related to changes in one participant’s understandings of the creative NOS when experiencing an implicit approach to NOS in the context of an authentic research experience in science. Part of the reason for the limited epistemic involvement of the other four case study participants of this current study was that they were engaging in scientific research that was ongoing at the beginning of the AESP. They were therefore not engaged in the development of their respective research projects. In the previously mentioned study that did not link epistemic involvement to gains in NOS understandings, mentors and participants held explicit conversations regarding why such epistemic involvement was not a realistic possibility (Burgin et al., 2011). Given the lengthy timeframe of many authentic research projects and the limited time available during a summer research apprenticeship program, it is unrealistic to expect all participants to be epistemically involved in each stage of their research project from the development of a question to the arrival at a conclusion. In the present

study, perhaps if mentor scientists and/or graduate students had clearly explained the history of the development of the research project to the participants placed with them, these participants would have had a better appreciation for the creativity that was involved in their project's design and why they were unable to make epistemic contributions to early stages of the research process.

One touted benefit of participating in authentic research experiences in science is that it allows the learner to collect “real” data that will be used for “real” purposes (Barab & Hay, 2001). With the possible exception of Jane, each of the case study participants were engaged in collecting data that were both meaningful and valuable to the laboratory group of which they were a part. The case study participants were subsequently involved in making interpretations of those data in order to arrive at conclusions. Such authentic action may have been related to the gains in understanding of the empirical nature of scientific knowledge in the cases of Tom and John, the subjective nature of scientific knowledge in the cases of Jennifer, Jane, Isabel and Joseph and the tentative nature of scientific knowledge in the cases of Jane, Isabel and John. Bleicher (1996) reported similar impacts on participant NOS understandings as they worked with their mentors to interpret data. These impacts were particularly powerful when the mentors of the participants held sophisticated NOS views.

Each case study participant experienced a level of collaboration in their research placement when it came to making decisions regarding how to best report their findings. This was particularly noticeable in the cases of Jennifer and John. Jennifer experienced growth in her understandings of the subjective nature of scientific knowledge that could be linked to the levels of collaboration that she experienced in her laboratory placement.

Additional research has indicated that collaboration is an important experiential aspect in research apprenticeship experiences that may be linked to desired outcomes of participation such as the development of informed NOS understandings (Burgin et al., 2011). Although other research has indicated discrepancies between how science in action was portrayed in the laboratory and how learners presented their research findings (Van Eijck et al., 2009; Hsu et al., 2010), no such disconnect was noted in this study. For example, both Jennifer and John attended regular laboratory group meetings where graduate students critiqued each other's research presentations and both of them were observed to give presentations that were very much like those that were given in their group meetings and that accurately reflected what occurred in their laboratory settings. Additionally, Jennifer and her mentor were observed as they collaborated on how to create a research poster. Jennifer then took this advice and as a result, her poster closely resembled others that were displayed in her laboratory setting.

In summary, the case study participants in this study were engaged in action that represented the typical actions engaged in by their graduate student mentors to varying degrees. This authentic action carried with it implicit messages regarding certain NOS aspects namely the empirical, creative, subjective and tentative nature of scientific knowledge in addition to the myth of the scientific method.

Treatment/mentorship

The implicit NOS messages received through authentic action took on greater meaning for the case study participants when the ways in which their mentors treated them were likewise genuine. Although Barab and Hay (2001) described authentic experiences in science as opportunities to work side-by-side with expert scientists, in the context of the AESP, like the setting investigated by Bleicher (1996), the mentorship

of the case study participants was facilitated primarily by graduate students. The quality of this mentorship was viewed to be authentic if the graduate student mentor valued both the participant and the work that they were contributing in ways that were similar to how they and their work were valued by the PI that they were working under.

Of all the case study participants, Jane was treated in the least authentic way by her mentors. This treatment was at least partially a result of her unwillingness to participate within the laboratory group. Neither the PI of Jane's laboratory or her graduate student mentor recognized contributions that Jane made to their research. Additionally, they did not trust the quality of the data that she collected. Jane subsequently did not experience high levels of authentic action as her mentors did not allow her to engage in such activity. Jane is contrasted with Joseph whose graduate student mentor and PI recognized the strengths that he brought into the lab and valued his findings. This is evident in that Joseph was going to be included as a co-author on multiple scientific research articles by his PI in the future. Because Joseph's mentors recognized the contributions that he could make to the development of his research project and allowed him the opportunity to do so, he engaged in more authentic action than any other case study participant. Jane and Joseph's stories account for why treatment is linked to action on Figure 5-3. When students were treated authentically, they were more likely to engage in authentic action that carried implicit NOS messages.

Feelings/identity

Four of the six case study participants in this study (Tom, Jennifer, John and Joseph) developed strong identities of themselves as authentic participants of science within their laboratory placements during the AESP. These identities will be described as science identities. A wealth of empirical literature supports the findings of the current

study related to the development of science identities. For example, engaging in the practices of science has been observed to impact the development of a positive science identity even in the context of a school science setting (O'Neill & Polman, 2004; Tan & Barton, 2008). Tan and Barton (2008) describe in particular how girls develop fluid science identities in school science settings as they engage in the practices of science. Outside of school settings, science identities of girls were impacted as they worked with professional scientists and had opportunities to see how these scientists were genuine human beings who were both personal and sociable (Farland-Smith, 2009; 2012). Research related to authentic research experiences in science for undergraduate students reports that participants were able to think and work in ways that were similar to those of scientists (Seymour et al., 2004) and that the accompanying science identity development resulted in increased confidence to work in research laboratories (Hunter et al., 2007).

Like the results of the research cited above, the case study participants in the current study developed positive science identities as they worked with professional researchers in laboratory contexts. Figure 5-3 illustrates how participant characteristics such as authentic feelings related to science identities were connected to both the ways in which the participants were treated by their mentors and the action that they engaged in. In the case of Joseph, the graduate students fully included him in every aspect of their laboratory culture. As a result, Joseph developed a positive science self-identity to the point where he viewed himself as a scientist. Tom, likewise, was treated in highly authentic ways that impacted his science identity. He recognized that the work that he was doing was exactly like what any other graduate student would do in his laboratory.

In that regard, his action influenced his feeling that he was an authentic member of the laboratory group. Additionally, when participants like Tom, Jennifer, John and Joseph developed strong science identities, the action that they engaged in took on new levels of meaning. They began to recognize that the work that they were doing was genuine and valuable. When this happened, the implicit messages carried through such authentic action were quite powerful in influencing the participants' NOS ideas.

Implications

For Authentic Research Experiences

There are a number of implications from this research study for authentic research experiences designed for high school learners. One implication regards the strength of the explicit/reflective approach to NOS teaching and learning over the other two, more implicit, approaches that were investigated. Research has demonstrated the superior benefits of the explicit/reflective approach when compared to an implicit approach in a traditional school science setting, but no study other than the current one has systematically compared multiple approaches to NOS teaching and learning in a setting like the AESP (Khishfe & Abd-El-Khalick, 2008; Yacoubian & BouJaoude, 2010). Other research has demonstrated the effectiveness of an explicit/reflective approach in the context of authentic research experiences but has not compared the students participating in such an approach to students experiencing a different approach (e.g. Charney et al., 2007; Schwartz et al., 2004).

Although the categorical data analysis revealed that the participants of the explicit/reflective seminar experienced significant growth in their understandings of NOS when compared to the participants of the other two seminars, it also revealed that not all NOS aspects were equally impacted. In fact, only the participants' understandings of the

distinction between theory and law and the myth of the scientific method were significantly impacted. The implication of this finding is that certain aspects of NOS may be more likely to be impacted as a result of an explicit approach in this context.

It is true that members of both the reflective and the implicit seminar experienced positive change in their understandings of many NOS aspects (Table 4-4). However, many of the students in these same seminars also experienced negative change in their NOS understandings. It follows that, in this context, implicit messages received through laboratory placements had the power to influence conceptions of NOS both positively and negatively. Although, no case study participants exhibited negative change in their understandings of NOS, those that exhibited positive change who were members of either the reflective or the implicit seminar also experienced supportive laboratory environments. Within these supportive environments, authentic action when combined with authentic treatment and/or the development of a science identity could be linked to positive changes in NOS ideas. The benefits of being placed in supportive laboratory environments that are collaborative, involve learners epistemically in the research process and allow for NOS conversations to occur between mentor scientists and the learner have been reported elsewhere and add strength to this implication (Bell et al., 2003; Burgin et al., 2011).

An additional implication of this research for programs like the AESP is that in the context of authentic research through apprenticeships, isolated reflection through journal entries has no perceived benefits apart from explicit NOS activities in impacting NOS understandings. Joseph clearly articulated that for him, it was the action occurring in his laboratory that impacted his understandings and not the reflective journal entries.

Isabel reported that through responding to the journal prompts she maintained naïve views about the myth of the scientific method. Categorical data analysis similarly revealed that there was no statistically significant difference between changes in NOS understandings for the members of the reflective and the implicit seminars. Therefore, reflection alone was not a particularly effective way to achieve increased levels of sophistication in the NOS understandings of participants of an authentic research experience in science.

Finally, a large number of students experienced no change in their understandings of NOS as revealed through the ISS (Table 4-4). This speaks to the large resistance to changes in NOS understandings held by high school students even in highly authentic contexts like research apprenticeship programs.

For Science Education

Research has demonstrated that implicit messages carried through participation in inquiry-based activities in traditional school science classrooms are not particularly effective in influencing participant NOS understandings (e.g. Moss, 2001; Sandoval & Morrison, 2003; Khishfe & Abd-El-Khalick, 2002). In contrast to these findings, the current study implies that implicit messages carried through authentic research experiences in supportive laboratory environments do have the potential to impact NOS ideas. Such a finding is consistent with other empirical studies demonstrating positive impacts from implicit messages on certain NOS ideas in the context of authentic scientific research (e.g. Ritchie & Rigano, 1996; Richmond & Kurth, 1999). This speaks to differences in the canonical authenticity between school science inquiry experiences and professional scientific research (Chinn & Malhotra, 2002; Hofstein & Lunetta, 2004).

Perhaps if school science laboratory work were more representative of professional science, then implicit NOS messages would be more influential.

A final implication for science education concerns the assessment of NOS. For the case study participants, written survey responses were not always consistent with verbal elaborations on those responses given through open-ended survey interviews (Table 4-9). John in particular discussed being intimidated by the written survey and felt like it was a test. In this study, interview data were prioritized over written data when rating participant NOS ideas. Interview data in this case were richer and much more detailed than many of the brief written responses given on the survey itself. Survey data collected through instruments such as the VNOS then carry some limitations. If students are given opportunities to expand upon their written responses, then a clearer picture of their NOS ideas can potentially emerge.

Recommendations

For Developers of Authentic Research Experiences

The implications just discussed lead to a number of recommendations for the developers of authentic research experiences in science. The first recommendation would be for developers of authentic research experiences to clearly articulate the goals of their program and then to design programmatic features accordingly in order to reach those goals. In the case of the AESP, the development of sophisticated NOS understandings was a goal that the administrators of the program clearly expressed to the researcher, but was not one that was explicitly stated on any program publications or marketing materials. Even though a goal of the program was to positively impact participant NOS ideas, no features of the program were explicitly designed in order to do so prior to the development of the explicit/reflective intervention seminar for the

current study. Based on the findings of this study, it is recommended that this program and others like it provide explicit/reflective NOS opportunities to participants through similarly designed seminars.

However, in some authentic research programs in science, the opportunity to design an explicit/reflective seminar may not exist. In these cases it becomes increasingly important that students be placed in highly supportive laboratory environments. Even when explicit/reflective seminars are available, participants still should be intentionally placed in desirable laboratory contexts in order to avoid mixed messages about NOS.

Laboratory placements ought to engage the participant in authentic action including but not limited to epistemic involvement in the research process as well collaboration within a laboratory group team. Additionally, graduate student mentors should go out of their way to treat the participant in the same way that they themselves are treated by the PI of the laboratory. Participants may then develop positive science identities which may further impact the ways in which they view the work that they are engaging in and subsequently may strengthen the positive implicit NOS messages that they receive through such participation in authentic action. Mentors should also be explicit with their students about the history of the project that they are working on. In this way, the participant may come to appreciate the creativity that was involved in the development of the project even if he or she was not around to contribute epistemically to its design. It is also recommended that mentor scientists and graduate students have explicit NOS conversations with their students that may facilitate reflection on the research that they are engaged in and how it is representative of the ways in which

knowledge is developed in science. Research has demonstrated the importance of explicit NOS conversations between mentors and participant learners working in their laboratories (Bell et al., 2003; Bleicher, 1996).

When the development of NOS is a goal of an research apprenticeship program, it is recommended that the facilitators of the program recognize the important role that is played by the mentor scientists and graduate students in achieving this goal. An orientation meeting could be held for mentors prior to start of the program in order to facilitate related conversations. Such an orientation would provide an opportunity to discuss findings of empirical research indicating influential features of laboratory environments that may carry implicit NOS messages. Materials summarizing research findings could be distributed to mentors in this meeting. Mentors could then brainstorm ways in which they could provide both positive explicit and implicit NOS messages to the participants who would be placed with them in their laboratories. Part of the purposes of such an orientation would be to raise awareness of the importance of authenticity within laboratory placements and to allow for the developers of the program and the mentor scientists and graduate students to create a plan for maximizing the authenticity experienced by the program participants placed within their laboratories. Specifically, discussions related to authentic forms of action that students can meaningfully participate in would take place in this orientation meeting. The importance of the participant understanding the ways in which their research project developed would be stressed particularly when the participant would be unable to participate in these early stages of research. Additionally, conversations related to the way in which mentors treat students and how the quality of that treatment is related to the

development of science identities would be held. Finally, ways in which mentors could recognize the strengths and abilities that participants bring with them to the program would be discussed. For example, mentors could be provided with pre-experience NOS assessments of the participants placed with them in order to recognize and target certain NOS aspects to have about which to hold explicit conversations with the participants. Mentors could also be provided with application materials from the participants placed with them in order to familiarize themselves with the prior experiences of the participants. This would help the mentors to identify the interests of the participants and their entering abilities to contribute meaningfully to the work of the laboratory group.

For School Science

A few recommendations are also suggested for school science based on the findings of this study. The first is for school science laboratory experiences to be modified in order to more accurately reflect the workings of professional scientists. The typical student in a school science setting will most likely never have an opportunity to participate in a program like the AESP. It is important therefore for them to have opportunities to engage in the practices of professional science while in traditional science settings. Students should be given opportunities to pose ill-structured questions and design scientific investigations to explore those questions in the traditional science classroom. It is recognized that the institutional constraints of a typical secondary science classroom, such as the pressures faced to prepare students for high-stakes assessments by covering massive amounts of scientific content in a short amount of time, make it challenging to implement full open-ended inquiry experiences regularly during an academic school year. Therefore it is recommended that students have such

an experience at least once a year. Additionally, students should be engaged in collaboration and discourse practices such as argumentation that model the interactions of working professional scientists. Students in traditional settings should also have opportunities to collect data that serve a valuable and meaningful purpose to the scientific community. Student Science Partnerships (SSPs) such as Forest Watch and Global Learning and Observations to Benefit the Environment (GLOBE) could facilitate such relationships between scientists and traditional classroom science learners (Lawless & Rock, 1998; Means, 1998).

It is recognized that traditional laboratory experiences that do not engage the learner in the full authentic range of scientific practices still serve a valuable purpose. Even if a student is conducting a chemistry laboratory activity that has a known outcome, the results of which are not meaningful to the larger scientific community, that student may still gain valuable content knowledge and learn important science process skills. In occasions such as this, it is recommended that the science teacher be explicit about the purposes of the activity and how it does not accurately reflect the actual workings of a professional scientist.

Limitations

Although limitations of the study were identified prior to data collection and discussed in Chapter 1, a few limitations emerged during the research process that warrant discussion here. The first of these limitations regards the approaches employed in each of the three seminars. Although observations were conducted in each seminar to ensure that NOS ideas were only being explicitly addressed in the explicit/reflective seminar, there was no feasible way for the researcher to be present at all times during all three of the seminars as they were being run concurrently. Therefore, there is a

chance, albeit a small one, that NOS aspects were addressed to a certain degree in the reflective and in the implicit seminars. An orientation meeting held with the graduate instructors of all three seminars where they were briefed on the design of the study most likely accounted for this limitation.

The results of the categorical data analysis indicated that only understandings of the distinctions between theory and law in science, the myth of the scientific method and possibly of the social-embedded nature of scientific knowledge were positively impacted in significant ways for the members of the explicit/reflective seminar as a whole. It is not known if this impact was a result of these aspects being less resistant to change for the participants or if the instructors of the seminar just did a better job explicitly addressing these three NOS aspects in comparison to the others.

There were also limitations to the use of the ISS as the sole means to assess participant NOS ideas. First, only the case study participants were interviewed about their responses. The analysis of these interviews was only partially consistent with an analysis of the written science surveys themselves. Therefore the results of the categorical data analysis of the written survey responses are somewhat tentative. The only way to account for this would have been to conduct survey interviews with all 30 of the participants. Secondly, there were limitations to the assigning of ratings to the responses given on the ISS. Although a rubric was developed to assist in the rating process (Appendix F), two independent raters still had to discuss each response to each survey in order to reach consensus. Recent efforts have been made to develop a validated coding rubric for use with the VNOS (Abd-El-Khalick, Belarmino & Summers,

2012). The use of such a rubric may have increased the trustworthiness of the claims made in this report.

Additionally, the case study participants were selected very early during the data collection process based on a preliminary analysis of responses from the first administration of the Ideas about Science Survey. The NOS ratings used to make decisions regarding whom to include as a case study participants were based on Sandoval's (2005) epistemological themes rather than the Lederman et al. (2002) NOS aspects that were ultimately used. It is uncertain if a different set of case study participants would have been selected if a different coding rubric had been utilized.

A related limitation is that observational and semi-structured interview data were only collected with the six case study participants, none of whom exhibited negative changes in their NOS understandings. There is therefore no evidence for what factors of specific laboratory placements if any negatively influenced the NOS understandings of the non-case study participants who experienced such change. The only way to account for this would have been to conduct all methods of data collection and analysis with all 30 of the participants.

Finally, the observational data collected from the six case study participants was limited in that often, as was the case with Jane and Isabel, there was not much to observe in the laboratory. More time spent in each laboratory during occasions when research practices were actually being conducted would have increased the understandings regarding the authenticity of each laboratory placement.

Suggestions for Future Research

The results of this study indicate a need for future research in a number of related areas. First, it is unclear how the effectiveness of the explicit/reflective approach

employed in this context would compare to the same approach utilized in a traditional school science classroom. In other words, how would the change in NOS understandings compare between students experiencing the explicit/reflective activities in the context of the AESP and in a school science context? Studies have demonstrated the effectiveness of explicit/reflective approaches in school settings (e.g. Khishfe, 2008), but would this effectiveness actually increase when students are given a uniquely authentic research experience like a research apprenticeship on which to reflect?

Secondly, it would be interesting to investigate how secondary learners would receive implicit messages through school science inquiry activities that were modified to more accurately reflect the practices of working scientists. Perhaps if traditional laboratory activities were restructured to allow for more authentic action on the part of the learner including the proposing of ill-structured research questions and the opportunity to investigate those questions through means other than the scientific method, implicit messages would be more influential than research has demonstrated them to be in school science settings (Khishfe & Abd-El-Khalick, 2002).

Third, future research could explore other means of assessing learner NOS understandings through focused observations and interview protocols that are more highly situated within the learner's own experiences conducting scientific research. Such assessments would perhaps do a better job assessing practical epistemologies (Sandoval, 2005) of science held by participants of research apprenticeship programs. These practical epistemologies could then be compared to formal epistemologies revealed through traditional NOS instruments such as the VNOS in order to determine if practical and formal epistemologies of science truly overlap in this specific context.

Fourth, it would be useful to explore the persistence of the NOS gains experienced by the participants of this research study over time. Stake and Mares (2005) demonstrated that the confidence to do science on the part of participants of a research experience in science actually increased upon their return to the traditional classroom. It is unknown if a similar increase in NOS understandings would occur as the participants had more time to reflect on their experiences in programs such as the AESP.

Fifth, it would be beneficial to investigate the NOS views of the mentor scientists and graduate students to look at how the sophistication of their perspectives relates to the implicit messages received by the participants placed in their laboratories. Related research could be done to investigate the impacts of professional development opportunities designed for these mentor scientists on the NOS views of the participants. Such research might carry with it implications regarding the importance of NOS instruction embedded in teacher education programs, if sophisticated NOS understandings of mentor scientists are related to the development of informed NOS understandings for the participants of authentic research experiences who are placed in their laboratories.

Conclusion

The results of this study challenge some of the existing research in science education. For example, the results do indicate the potential for implicit messages carried through participation in highly authentic experiences to impact learner conceptions of NOS. Lederman (2007) suggests that empirical literature demonstrates conclusively that implicit approaches are not as effective as explicit approaches. Similarly, Bell and colleagues (2003) report that the impacts from an implicit approach on participant NOS ideas were negligible in a context very similar to the AESP.

However, in the present study, the implicit messages received by the six case study participants were rather effective in influencing their understandings of certain NOS ideas.

Additionally, the findings of this study show that certain NOS understandings such as the empirical nature of scientific knowledge and the creative nature of scientific knowledge are more likely to be influenced by implicit messages than are understandings of the differences between theories and laws in science. Such a result speaks to the idea that NOS approaches are not equally effective in influencing all aspects of NOS, and that the most powerful way to influence such understandings may be through a combination of explicit and implicit approaches. This research suggests that students should be explicitly introduced to NOS aspects and then provided with authentic experiences practicing science on which to reflect on those aspects. These experiences have the potential to carry with them implicit NOS messages that may support explicit messages received through an explicit/reflective approach. This study demonstrates that such a model is effective in the context of authentic research experiences in science.

In closing, this study supports the suggestions made in recent reform documents to increasingly engage students in the practices of science and that in so doing, students may develop more sophisticated understandings of the ways in which knowledge is developed in science (NRC, 2012). Based on the findings of existing literature and the results of this study, learning science by doing science is most effective when the activity is canonically authentic. Therefore, students should have experiences engaging in authentic scientific research both in and out of school. Future

empirical research is needed to further substantiate this claim. A number of specific research inquiries are suggested that could guide the science education community as they explore these important issues.

APPENDIX A REFLECTIVE JOURNAL PROMPTS

Week 2: (2 seminars)

Prompt 1: Describe the culture of your laboratory environment including the personalities and background of the members of your lab group. Do you think this culture influences the work that takes place in your lab? If so, explain why you think this way and how you think the work is influenced. If you do not think that the culture of the lab influences the work, explain why. (Construction of scientific knowledge)

Prompt 2: Explain how you have observed cooperation, collaboration and/or competition in your laboratory placement. You may have observed this within your laboratory and/or in how your laboratory interacts with those outside of your laboratory. How do these aspects of your laboratory placement contribute to the generation of scientific knowledge? (Construction of scientific knowledge)

Week 3: (2 seminars)

Prompt 3: How are you collecting data in your lab? How do you think other scientists would perform similar research to your own? Explain using specific examples. (Diversity of scientific methods)

Prompt 4: Are you using the scientific method to answer the question that is driving your research? Why or why not? Which parts of the scientific method are you using? Would you have to use the scientific method in your research? Could there be other ways of answering your question? Explain using specific examples. (Diversity of scientific methods)

Week 4: (2 seminars)

Prompt 5: What is a scientific theory? What is a scientific law? How confident are you of your definitions? Are any theories and/or laws involved in your personal scientific research? What are they? How certain are they? Are one of the two forms of scientific knowledge more certain than the other? Explain (Forms of scientific knowledge)

Prompt 6: What is a model in science? Are there different types of models in science? Explain. Have you relied on any models in your personal research project? If so, explain them and why you have relied on models. If not, why? How certain are the models you are using? Explain. (Forms of scientific knowledge)

Week 5: (2 seminars)

Prompt 7: What is an observation in science? What is an inference in science? Provide examples of both from your own project. What are the implications of observation and inference on the certainty of scientific knowledge? (Forms of scientific knowledge, Scientific knowledge varies in certainty)

Prompt 8: How certain are you of the results you are obtaining in your personal research project? Explain the reason for your response with specific examples from your research project. What might limit the certainty of your results? Is there anything other than human error that may impact the certainty of your results? Explain. (Scientific knowledge varies in certainty)

Week 6: (1 seminar)

Prompt 9: Do you think the results of your project might one day be understood differently than you understand them now? Explain why or why not. Can there be multiple interpretations of your data? Explain why or why not. How often are multiple explanations of the same evidence possible in science? Explain your answer. (Scientific knowledge varies in certainty)

Prompt 10: I would like you to spend some time reflecting on the reflection process. What if any was the impact of responding to these prompts? Did you find this writing process to be valuable? In what ways?

APPENDIX B
IDEAS ABOUT SCIENCE SURVEY AND FOLLOW-UP INTERVIEW PROTOCOL

Instructions

- Please answer each of the following questions. You can use all the space provided and the backs of the pages to answer a question.
 - Some questions have more than one part. Please make sure you write answers for each part.
 - This is not a test and will not be graded. There are no “right” or “wrong” answers to the following questions. I am only interested in your ideas relating to the following questions.
1. (a) What is science?

(b) What do scientists do? How do they accomplish this work?
 2. What makes science (or a scientific discipline such as physics, biology, etc.) different from other subject/disciplines (art, history, philosophy, etc.)? (Forms of scientific knowledge)
 3. Some think scientific knowledge is constructed. Others think it is discovered. Which do you agree with and why? (Construction of scientific knowledge)
 4. Scientists produce scientific knowledge. Do you think this knowledge may change in the future? Explain your answer and give an example. (Construction of scientific knowledge, Scientific knowledge varies in certainty)
 5. (a) Scientists agree that about 65 millions of years ago the dinosaurs became extinct. However, scientists disagree about what caused this to happen. Why do you think they disagree even though they all have the same information?

(b) If a scientist wants to persuade other scientists of their theory of dinosaur extinction, what do they have to do to convince them? Explain your answer. (Construction of scientific knowledge, Scientific knowledge varies in certainty)
 6. In order to predict the weather, weather persons collect different types of information. Often they produce computer models of different weather patterns.

(a) Do you think weather persons are certain (sure) about the computer models of the weather patterns?

(b) Why or why not? (Forms of scientific knowledge, Scientific knowledge varies in certainty)

7. The model of the inside of the Earth shows that the Earth is made up of layers called the crust, upper mantle, mantle, outer core and the inner core. Does the model of the layers of the Earth *exactly* represent how the inside of the Earth looks? Explain your answer. (Forms of scientific knowledge, Scientific knowledge varies in certainty)
8. The previous two questions asked about scientific models. What is a scientific model?
9. (a) What is the “scientific method”?

(b) Do all scientists use the “scientific method”? If so, why? If not, what else do they do?
10. Scientists try to find answers to their questions by doing investigations / experiments. Do you think that scientists use their imaginations and creativity when they do these investigations / experiments?
(a) If **NO**, explain why.

(b) If **YES**, in what part(s) of their investigations (planning, experimenting, making observations, analysis of data, interpretation, reporting results, etc.) do you think they use their imagination and creativity? Give examples if you can. (Construction of scientific knowledge, Diversity of scientific methods)
11. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example. (Forms of scientific knowledge)
12. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like? (Forms of scientific knowledge, Scientific knowledge varies in certainty)
13. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change? Explain and give an example.

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

(b) If you believe that scientific theories do change, explain why theories change. Explain why we bother to learn scientific theories. Defend your answer with examples. (Forms of scientific knowledge, Scientific knowledge varies in certainty)

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

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

(b) If you believe that science is universal, explain why. Defend your answer with examples. (Construction of scientific knowledge)

15. (For 2nd administration of survey). How often did you talk about the things on this questionnaire with your mentor during this experience? Describe the specifics of any conversation you may have had.

16. (For 2nd administration of survey). How often did you talk about the things on this questionnaire with your peers outside of your seminar group during this experience? Describe the specifics of any conversation you may have had.

Science survey follow-up interview protocol (Adapted from Bell et al., 2003; Abd-El-Khalick, 1998).

1. What did you mean by your response to question number (refers to a specific question on the questionnaire)?
2. After Question 1-2: Define “creativity” and “imagination”. How are science and art similar or dissimilar?
3. After Question 1-5: How much evidence is enough to prove a certain claim?
4. After Question 1-9: Do all scientists use a specific step-wise procedure in conducting science? Please elaborate.
5. After Question 1-11: In terms of status and significance of scientific knowledge, how would you rank theory and law?
6. After Question 1-13: Why do we invest time and energy to grasp these theories? Which comes first observation or theory?
7. After Question 1-14: Do political/social/cultural differences influence the interpretation of scientific results? How so?
8. Has your mentor ever talked to you about the kinds of things on this questionnaire? Please explain.

APPENDIX C

CASE STUDY SEMI-STRUCTURED INTERVIEW PROTOCOLS

Semi-structured Interview Protocol 1 (Case study students). Week 3

1. What kind of “science experiences” have you had prior to participating in AESP? (e.g. science camps, internships, parent is a scientist, science fair, etc.)
2. What kind of science courses have you taken in high school? Do you feel that these courses have prepared you for this experience? In what ways? Explain
3. What are your plans after high school? If you are going to college, what would you like to study? What professions are you considering? Do you see yourself studying/doing/participating in science in any way? What has influenced these plans?
4. Can you tell me about the work that you are doing as a part of this experience? What kind of research goes on in the lab you are working in? What kinds of lab processes and/or equipment are you using? Do you find this work interesting? Why or Why not?
5. Would you say that you feel like a working contributor in the lab, an outsider just visiting, or somewhere in between? Explain.
6. How do you feel about your abilities to work in the lab? Do you feel comfortable using the equipment and procedures of the lab you are working in? Do you have a good understanding of the science content you are investigating? What has contributed to your responses?
7. Have you had any role in determining the kind of research that you are doing? Research questions? Procedural Designs? Are you working on someone’s pre-existing project? Explain your responses.
8. Describe the nature of collaboration in your laboratory group. Was this what you were expecting? Explain.
9. Describe a typical day’s work in your laboratory.
10. Have any specific aspects of your experience influenced the way you think about science and the work that scientists do? Explain these aspects.
11. Is there anything else you would like to share about your experience thus far?

Semi-structured Interview Protocol 2 (Case study students). Week 5

Revised 7/12/11 based on initial coding of first three observations and 1st semi-structured interview. Questions 2,5,7,11,13,14,16,17 added

1. Has your interest in your project changed over the past few weeks? Explain.
2. What is the purpose of your project?
3. How has your research progressed over the past few weeks? Have you encountered any challenges/difficulties? Explain. How have you responded to these?
4. Have you had to modify any part of your experimental plan? Describe this process? How did you know what to do?
5. Are you following any established protocols in your lab? Explain them to me. Where do you think they came from? Have they ever been modified?

6. What sort of data have you collected so far? Have you done any analysis? What sort? Do you have any preliminary results? What are they? How close are you to completion? Will your project ever be complete?
7. Do you ever have down time in your lab? Why? Do trials take a long time to run? What do you do while you wait? Do you feel like you are using your time productively?
8. How has your comfort level in your lab environment changed since we last spoke?
9. Last time I asked you if you felt like a working contributor in the lab, an outsider just visiting, or somewhere in between. Do you still feel the same way as you did last time? Explain.
10. Describe the relationships you have developed with other people in your laboratory. Has your relationship with your mentor grown? How so?
11. You are mainly being mentored by a graduate student researcher. How do you feel about that? Do you feel like you interact enough with the PI of your lab? How often do you see the PI?
12. Describe a typical conversation you might have with your mentor.
13. Do you feel comfortable asking questions to your mentor? How do you feel about the way they respond to your questions?
14. Have you ever made a mistake in your laboratory? How did your mentor respond to you if you did?
15. Have you experienced more collaboration in your work? Explain why or why not.
16. Some students are working with another AESP student in the same lab. If you are, how do you feel about this? If you aren't, how do you feel about this? What do you think are the advantages and disadvantages of working with another AESP student?
17. Has the way you think about science and/or the work that scientists do changed at all over the summer so far? In what ways?
18. Have any specific aspects of your experience influenced the way you think about science and the work that scientists do? Explain these aspects.
19. Is there anything else you would like to share about your experience thus far?

Semi-structured Interview Protocol 3 (Case study students). Week 7

Revised 7/25/11 by adding questions 2,3,4,5,9,10 and 13 following data collection and initial analysis of earlier observations

1. Did you make any changes to your research plan since we last spoke? Describe any modifications you made and how you went about doing so.
2. Did you finish your project? Why or why not?
3. Have you been working right up to the end, or were you done with data collection a while back? What have you been doing with your time?
4. What are your results? How did you achieve them?
5. Did you make any statistical analysis of your data? Did you have to make decisions about reducing the data, cutting out some of the data etc.? How did

you make those decisions? Was there any error in your results? Did you run tests of significance? What does that mean?

6. Describe the feelings you have about your results? Are you satisfied? Proud? What has contributed to these feelings?
7. What do your results mean? What are the broader implications of your research if any?
8. Are your results valuable to your lab group? In what ways? How do you know?
9. How have you chosen to represent your results in your poster/presentation/paper? What led to these decisions?
10. Did you have the opportunity to observe other grad students/ members of your laboratory group giving research presentations? Explain this.
11. How did your interest in your project change or not change over the course of your experience? Explain.
12. Describe the final levels of collaboration that you experienced in your lab.
13. Did you have or will you have any final interactions with the PI of your lab?
14. How significant are the relationships that you have developed? Who will you miss? Who will miss you? Why do you feel this way?
15. In your own words, what has been the impact of this program for you personally? How has it influenced you?
16. Have any specific aspects of your experience influenced the way you think about science and the work that scientists do? Explain these aspects.
17. Is there anything else you would like to share about your experience?

APPENDIX D
CASE STUDY OBSERVATION PROTOCOL

Participant name: _____

Date: _____ Time: _____

Nature of work (Description of the laboratory techniques and procedures that the apprentice is engaged in):

Epistemic Involvement (Observational evidence of apprentice participation or lack thereof in the formulation of research questions and/or design of methodological protocols. e.g. Is the student involved in any decision making regarding the research process?):

Collaboration (Record of apprentice engagement socially with others in the lab. e.g. Verbatim conversations, cooperative group work, shared responsibility for tasks etc.):

Mentor Involvement (Record of mentor/apprentice interactions. e.g. Verbatim conversations, mentor help given etc.):

Observer perceptions of apprentice demeanor (e.g. Engaged? Happy? Irritated? Busy? Bored? Etc.):

Observer perceptions of mentor demeanor (e.g. Willing? Available? Annoyed? Etc.):

Record of conversations between observer and apprentice (e.g. What are you doing today? How is your research coming along? Are you liking it? Etc.):

Record of conversations between observer and mentor (e.g. How is your apprentice doing in your lab? What sort of support are you planning on giving your apprentice today? Etc.):

APPENDIX E

MENTOR SEMI-STRUCTURED INTERVIEW PROTOCOL

Modified 8/3/2011 to account for observation data

Grad Student Questions

1. Have you ever worked with high school students before? in your lab?
2. What were your reasons for taking a high school student in your lab this summer?
3. What benefits do you think a high school student experiences through participation in this program? Explain with specific examples.
4. In what role did you work with this summer's student? Explain.
5. Could you briefly describe the project the student worked on this summer?
6. To what degree did the student take ownership of his or her project? Explain.
7. Did the student make any personal contributions to the formulation of the research question/ design of the project? Why or why not? What were the reasons for this level of involvement?
8. Did the student seem to feel comfortable working with your lab group? What evidence leads you to this understanding?
9. Would you say that the student felt like a working contributor in the lab, an outsider just visiting, or somewhere in between? Explain.
10. In your estimation, what were the reasons for such student positioning?
11. Did you feel like the student was a valuable part of your team?
12. Were you ever frustrated or lose your patience with the student when they made mistakes? How did you respond?
13. What will you do with the results of your students project?
14. Did you observe any changes in the student's understandings of the scientific enterprise over the course of the summer? If so, in what ways?
15. What factors do you think contributed to these changes and/or their understanding of science? Explain.
16. Could you spend a few minutes telling me your personal philosophy of science? i.e. What is the status of scientific knowledge? How certain is it? What do scientists do? Do they always follow the scientific method? Is science universal or does it reflect the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced?
17. Did you ever talk with the student about your personal philosophy of science? Did any philosophical conversations come up?
18. Would you do this again?
19. How would you do it differently? Lessons learned?

PI Questions

1. How many years have you been hosting a student in your lab?
2. What are your reasons for hosting a student?
3. What benefits do you think a high school student experiences through participation in this program? Explain with specific examples.

4. In what role did you work with this summer's student? Explain.
5. Describe the nature of the scientific research that you do in your lab?
6. Did the student seem to feel comfortable working with your lab group? What evidence leads you to this understanding?
7. Would you say that the student felt like a working contributor in the lab, an outsider just visiting, or somewhere in between? Explain.
8. In your estimation, what were the reasons for such student positioning?
9. Did you feel like the student was a valuable part of your team?
10. What will your lab group do with the results of the student's research?
11. Did you observe any changes in the student's understandings of the scientific enterprise over the course of the summer? If so, in what ways?
12. What factors do you think contributed to these changes and/or their understanding of science? Explain.
13. Could you spend a few minutes telling me your personal philosophy of science? i.e. What is the status of scientific knowledge? How certain is it? What do scientists do? Do they always follow the scientific method? Is science universal or does it reflect the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced?
14. Did you ever talk with the student about your personal philosophy of science? Did any philosophical conversations come up?
15. Would you do this again?
16. How would you do it differently? Lessons learned?

APPENDIX F

IDEAS ABOUT SCIENCE SURVEY CODING RUBRIC

1. Empirical nature of scientific knowledge

Relevant Questions	Naïve	Mixture	Informed
1b, 5a, 5b, 6a, 6b, 7, 12, 13a, 13b	Students don't prioritize observations, inference, empirical evidence, or interpretation in establishing the claims of science. Scientific knowledge is about facts.	Students answer some questions from a naïve perspective and others from an informed perspective. Students may discuss the need of actually being present historically in order to know why dinosaurs became extinct.	Students understand that scientific knowledge is based on observations and filtered interpretations of those observations.

2. Differences between theories and laws:

Relevant Questions	Naïve	Mixture	Informed
4, 9, 11, 13a, 13b	Students see theories and laws as related in a hierarchy. Additionally, students may describe laws holding a higher status than theory.	Students answer some questions from a naïve perspective and others from an informed perspective.	Students conceptualize laws as descriptions of relationships and theories as inferred relationships. Theories and laws serve different purposes in science. They understand that theories and laws are equally well-established in science.

3. Creative and imaginative nature of scientific knowledge:

Relevant Questions	Naïve	Mixture	Informed
1b, 2, 10a, 10b	Students think that scientists' creativity is very limited. They may only acknowledge creativity to occur in the beginning phases of scientific research.	Students answer some questions from a naïve perspective and others from an informed perspective.	Creativity and imagination permeates all aspects from design and implementation to interpretation of results.

4. Scientific knowledge is subjective:

Relevant Questions	Naïve	Mixture	Informed
1a, 1b, 2, 5a, 5b, 14a, 14b	Students think that science is purely objective. They think that scientists are not influenced at all by their prior belief systems.	Students may acknowledge that science is both subjective and objective.	Students acknowledge that science is subjective, that is that scientists hold theoretical perspectives that influence their activity.

5. Scientific knowledge is socially and culturally embedded:

Relevant Questions	Naïve	Mixture	Informed
1a, 1b, 2, 5a, 5b, 14a, 14b	Students describe science as universal and uninfluenced by the culture surrounding it.	Students acknowledge both universal and socially and culturally embedded aspects of the generation of scientific knowledge.	Students acknowledge that science is socially and culturally embedded.

6. Scientific knowledge is tentative and subject to change:

Relevant Questions	Naïve	Mixture	Informed
4, 5a, 5b, 6,7, 11, 12, 13a, 13b	Students may believe that science knowledge is set in stone and never changes. Or they might believe that science is so relativistic that it is constantly in a state of change. Other students may believe that scientific knowledge can be proven with certainty. It is changing until it reaches an absolute state of authority.	Students answer some questions from a naïve perspective and others from an informed perspective.	Students acknowledge that when science changes it does so because of both new evidence and reinterpretation.

7. Myth of the scientific method:

Relevant Questions	Naïve	Mixture	Informed
1b, 9a, 9b, 10a, 10b	Students think that most scientists follow a prescribed step-wise procedure that results in correct established information when conducting scientific research.	Students answer some questions from a naïve perspective and others from an informed perspective.	Students acknowledge that the scientific method may be used at times for the purposes of experimentation but acknowledge that other scientists may perform scientific research in ways that does not resemble the scientific method. For example, observational studies, or just by trial and error methods. Students may describe that scientists use the method in unique ways by reordering or eliminating certain steps

8. Scientific knowledge is constructed (Sandoval, 2005)

Relevant Questions	Naïve	Mixture	Informed
3	Students think that scientific knowledge exists and is waiting to be discovered.	Students describe a mixture of both discovery and construction of knowledge.	Students discuss how scientists construct ideas and these constructions are and result in scientific knowledge.

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BIOGRAPHICAL SKETCH

Stephen Randall Burgin graduated from the University of Florida in 2002 with a bachelor's degree in chemistry. He then completed his master's degree in science education in 2003 from the University of Florida. Stephen then taught high school chemistry at the P.K. Yonge Developmental Research School in Gainesville, FL for six years. While teaching, Stephen earned his specialist's degree in science education in 2009 from the University of Florida.

Stephen's research interests center on authentic research experiences in science and their impact on learner understandings of nature of science. His work has been published in the Journal of Research in Science Teaching and Research in Science Education. This summer, an article of Stephen's, written for practicing science teachers, will be published in The Science Teacher. Stephen has presented his research at numerous international conferences for science education.

Upon completing his doctorate in the summer of 2012, Stephen will join the faculty of Old Dominion University in Norfolk, VA as an assistant professor of science education in the department of STEM Education and Professional studies within the College of Education. Stephen, his wife Rachael and his daughter Leah are very much looking forward to their move.