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Creating Links Between Students' Personal and Global Understandings of Nature of Science Through Research Apprenticeships

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ABSTRACT

The standard view of Nature of Science (NOS) is that the development of sophisticated understandings of professional science practice can and should be an explicit goal of science education in traditional school settings (Lederman, 1992; Lederman, 2007). This perspective implies that students have one working conception of NOS. Others suggest that the culture of the science classroom is so different from the culture of a working science lab that students may hold two distinct views of NOS (Hogan, 2000; Sandoval, 2005). We believe that secondary students experiences in scientific research apprenticeships have the potential to allow these learners to become members of a working science lab where they truly experience an authentic form of science. These experiences may bridge the gap between students' personal and global understandings of NOS. Implications for the teaching, learning, and assessment of NOS in these contexts is discussed and a research agenda is proposed.

KEYWORDS: Nature of Science; Authenticity; Research Apprenticeships

Araştırma Çıraklığı Aracılığıyla Öğrencilerin Bireysel ve Evrensel Bilimin Doğası Anlayışları Arasında Bağlantılar Oluşturma

ÖZET

Bilimin doğası ile ilgili genel görüşe göre profesyonel bilim uygulamaları hakkında üst düzeyde anlayış geliştirme geleneksel okul düzeninde fen eğitiminin açık ve anlaşılır bir hedefi olmalıdır (Lederman, 1992; Lederman, 2007). Bu bakış açısı öğrencilerin tek bir bilimin doğası anlayışına sahip olmasını ifade etmektedir. Bazılarına göre ise okullardaki fen sınıflarının kültürü bir bilim laboratuvarından o kadar farklıdır ki öğrenciler apayrı iki farklı bilimin doğası görüşüne sahip olabilirler (Hogan, 2000; Sandoval, 2005). Biz ise lise düzeyinde bilimsel çalışmalara asistanlık yapma deneyiminin bu öğrencilere bilimin doğasını doğrudan öğrenebilecekleri bir bilim laboratuvarının parçası olma imkanı sağlayacağına inanıyoruz. Bu deneyim öğrencilerin kişisel bilimin doğası anlayışları ile evrensel bilimin doğası anlayışı arasındaki farklılığı giderebilir. Bu deneyimin öğrenme, öğretme ve bilimin doğasını değerlendirme açısından etkileri tartışıldı ve bir araştırma gündemi önerildi.

ANAHTAR KELİMELER: Bilimin doğası, Otantik deneyim, Araştırma asistanlığı/çıraklığı

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INTRODUCTION

Student's conceptions of the epistemology of professional science are potentially quite distinct from the epistemological understandings of their own experiences practicing science in the context of traditional school settings (Hogan, 2000; Sandoval, 2005). We define science epistemology as the status of knowledge claims within the discipline of science and the cultural values and norms inherent in their development. Hereafter, this construct is referred to as Nature of Science (NOS). We draw from a situated learning perspective (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991; Sadler, 2009) in attempting to understand the distinctions between NOS understandings of professional science and those of personal science experiences. From this theoretical framework, the processes of knowing and learning are inseparable from the context in which they take place.

Our experiences in secondary science classrooms in the United States give us reason to believe that the culture of school science is often vastly different from the culture that prevails in a community of working professional scientists. It is not surprising then that student's personal conceptions of NOS, as informed by their own experiences in a less than authentic school context, may result in naïve understandings of professional NOS. It is a desirable goal of science educators to provide opportunities for learners to experience science in ways that are authentic in that they are more closely aligned to the culture of professional science (Chinn & Molhotra, 2002). This can be accomplished either by attempting to modify school science activities to be more authentic (Bencze & Hodson, 1999; Chinn & Molhotra, 2002) or by allowing students to experience the culture of science first hand through embedded experiences in working laboratories or through field experiences involving working scientists (Barab & Hay, 2001; Charney, Hmelo-Silver, Sofer, Neigeborn, Coletta, & Nemeroff, 2007; Helms, 1998; Richmond & Kurth, 1999). It is our belief that the constraints of school settings (time, administrative support, pressures created by an exhaustive list of required standards, etc.) limit the opportunities to participate in authentic science as defined by the culture of professional science. Therefore, embedded experiences in working science laboratories are among options that provide a more authentic experience than do science classrooms. These research apprenticeships may allow students to form personal NOS conceptions that are aligned to their conceptions of professional NOS. Research apprenticeships, then, may bridge the gap between these two ways of viewing NOS.

Nature of Science

What exactly constitutes appropriate understandings of NOS and of what benefit are such conceptions to the typical science learner? For many years, the science education community has been attempting to deconstruct NOS into component parts that can be examined individually and interdependently. Through these efforts, a number of individual lists of NOS aspects have been developed

(Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003; Sandoval, 2005; Schwartz & Lederman, 2008; Wong & Hodson, 2009). Although these various lists have varying numbers of component NOS aspects, they are all remarkably similar. Some features that they share in common include the idea that scientific knowledge is tentative (subject to change), that scientists use a diversity of methods relying on their creativity throughout the entire research process, and that scientific knowledge is created under the influence of a variety of socio-cultural factors. Some have questioned the extent to which this lists of NOS aspects overlap (Alters, 1997). Alters (1997) conducted a survey-based research study with nearly two hundred philosophers of science that illustrated a lack of consensus regarding their understandings of NOS. Others have reported significant concerns with this study including the fact that the research only took into account the perspectives of philosophers and not other stakeholders in science education, and that the esoteric positions held by these philosophers regarding the epistemology of science knowledge were not necessarily relevant to K-12 science education (Smith, Lederman, Bell, McComas, & Clough, 1997). More recently, NOS questionnaires and interviews with scientists, science philosphers, science historians and science educators have revealed that a good deal of consensus actually does exist regarding the standard aspects of NOS discussed above (Osborne, et al., 2003; Schwartz & Lederman, 2008; Wong & Hodson, 2009; Wong & Hodson, 2010). Although we believe that agreed upon lists of NOS aspects deemed important for K-12 science education are for the most part uncontroversial, we acknowledge, along with Lederman (2007), that no single “correct” list exists, but rather such lists are tentative just like the nature of the scientific knowledge that they are describing.

Why NOS?

Sophisticated NOS understandings are important components of national reform documents in the United States (AAAS, 1993; NRC, 1996). The prominent position of NOS in US standards and the frameworks for other nations is due to the widely held perspective that NOS understandings are crucial to the development of scientifically literate citizens. Although there is not an overwhelming amount of evidence to support this claim, some empirical research does point to the link between student held conceptions of NOS and decision making in the context of socio-scientific issues such as global climate change (Sadler, Chambers, & Zeidler, 2004; Zeidler, Walker, Ackett & Simmons, 2002). Another reason for placing emphasis on NOS as an explicit outcome of K-12 science education is the well-documented claim that students understandings of the tentativeness of scientific knowledge and the creative and social ways in which it is developed are significantly less than well-informed (Lederman, 1992; Lederman, 2007). We therefore believe that the development of sophisticated understandings of NOS is and should be a desired outcome of science education. Meaning is given to both the content and the process of science when students achieve this goal.

Implicit Versus Explicit Approaches to NOS Teaching

Although science educators, scientists, science teachers, policy makers and the like seem to agree on basic tenets included in NOS (Osborne et al., 2003) and the necessity of NOS instruction in K-12 education (AAAS, 1993; NRC, 1996), uncertainty remains regarding the identification of effective practices in the teaching, learning and assessment of this construct. Approaches for the teaching and learning of NOS have been broadly characterized as implicit or explicit. The implicit approach is based on an assumption that students will develop sophisticated understandings of NOS through participation in hands-on scientific inquiry experiences that do not explicitly address NOS aspects. Lawson (1982) seems to hold this perspective when he discusses student ability to develop sophisticated causal reasoning skills through participation in hypothesizing about cause and effect relationships in science. The effectiveness of this implicit approach in school settings has been empirically called into question elsewhere (Meichtry, 1992; Moss, 2001). Using a quantitative Likert scale assessment of NOS constructs administered to secondary students both at the beginning and the end of an inquiry-based curriculum in middle school biology relying on an implicit approach to NOS, Meichtry (1992) demonstrated that some student participants' understandings of NOS actually diminished in comparison to a group participating in a more traditional curriculum. Similarly, Moss (2001) used interview data to show that participation in a school-science partnership, based upon an implicit NOS instructional model, did not have an impact on student understandings of NOS.

The explicit-reflective approach to NOS was developed in response to the limited gains seen in implicit approaches (Akerson, Abd-El-Khalick, & Lederman, 2000; Akerson & Volrich, 2006; Khishfe & Abd-El-Khalick, 2002). The explicit-reflective approach to the teaching and learning of NOS involves explicit instruction of the agreed upon aspects of NOS and provides opportunities for students to reflect on their NOS understandings in conjunction with classroom-embedded inquiry activities. It should be noted that an explicit approach, as used here, does not necessarily refer to teacher-directed instruction. Rather, the approach deals with NOS understandings as desired cognitive outcomes that should be explicitly featured in teaching and learning activities that students engage in. Khishfe and Abd-El-Khalick (2002) specifically investigated the relationship between an implicit and an explicit-reflective approach to the teaching and learning of NOS. In their 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 tentative nature of science and the creative NOS in addition to other aspects prior to and following the intervention. One of these groups received no instruction that targeted NOS themes; therefore any gains in NOS understandings would have been achieved implicitly through participation in scientific inquiry. The other group was explicitly introduced to the targeted NOS aspects and discussed ways that these NOS aspects 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-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, we have questions regarding the transferability of these findings to more authentic contexts such as research apprenticeships. Of the six inquiry activities that these students participated in, four were simple experiments and none involved ill-defined problems. In fact, all of the inquiry activities were guided by questions that were provided to the students. 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 we find experiences like these to be far removed from the actual practice of working scientists. This may explain why students who participated in these activities without explicit instruction on target NOS aspects exhibited no development of deeper understandings of NOS as assessed by questionnaires that asked them about the practices of working scientists.

Assessing NOS

Assessing learner conceptions of NOS has historically been done using wide-scale quantitative instruments. The most widely used assessment is the Test On Understanding Science (TOUS), a 60 question multiple-choice test developed by Cooley and Klopfer (1961). The validity of these traditional assessments has been called into question on the basis of their poor construction and the developer bias inherent to them (Lederman, 2007; Lederman, Wade, & Bell, 1998). The suggestion has been made to move toward a more qualitative and open-ended approach to the assessment of NOS that allows learners to express their own views rather than their conformity to the perspectives of the developers of an assessment instrument (Lederman, Wade, & Bell, 1998). The View of Nature of Science (VNOS) questionnaire was developed as an assessment tool to address many of the perceived limitations of earlier instruments (Lederman et al., 2002). This questionnaire asks students for their written responses to a number of statements regarding the nature of professional science practice. Follow-up interviews are then conducted with a subset of participants to verify rater interpretations of student responses. Student conceptions on each targeted NOS aspect are given a qualitative rating of naïve, informed, or in transition.

Sandoval (2005) calls into question assessments like the VNOS which ask for students to discuss their views of science in contexts that are quite distinct from their own experiences with science. He suggests the need for a more ethnographic approach to the assessment of NOS that is embedded in the context of authentic scientific practice. Sandoval's approach involves using open-ended interviews and the study of student discourse and artifacts produced during student participation in science. According to Sandoval, assessments like the

VNOS are asking students about their impressions of the professional practice of science that is far removed from their own experiences. In discussing instruments like the VNOS, Sandoval suggests that they are based on an "assumed coherence of beliefs" between student perspectives of their own participation in science and their perspectives of professional science (Sandoval, 2005 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. If students hold distinct views of NOS in different contexts, then such an assumed coherence is not valid.

Personal Versus Global NOS

The above discussion related to the assessment of NOS conceptions raises an important issue in contemporary understandings of the field. There exists a growing concern that students may have more than one set of beliefs regarding NOS. Hogan (2000) suggests that students have both proximal and distal understandings of NOS. Students' proximal understandings of NOS involve perceptions of their own personal involvement in the generation of science knowledge. Distal understandings refer to student conceptions of professional science. Hogan suggests that many NOS research interventions are insensitive to the potential differences between these two conceptions. These interventions may be influencing students proximal understandings of NOS, but assessments used to gauge their impact focus almost exclusively on measures of distal NOS understandings without providing opportunities for students to make explicit connections to their own participation in science. Hogan recommends that science education research make a distinction between distal and proximal NOS understandings and investigate each independently before attempting to examine their interrelations. Sandoval (2005) makes a similar argument when he suggests that students hold both practical and formal epistemologies of science. Practical epistemologies (like proximal understandings) are students' ideas about their own inquiry and the knowledge creation it involves. Formal epistemologies (like distal understandings) are students' beliefs about professional science. Unlike Hogan (2000), Sandoval suggests that science education research should examine both practical epistemologies and formal epistemologies simultaneously in an effort to understand how they are related to each other.

In our own work, we are interested in better understanding ways in which students' practical and formal epistemologies may develop and the contexts in which growth in both areas may be supported. At least conceptually, it seems likely that opportunities for students to engage in authentic scientific practices may be ideal contexts for the growth of NOS ideas. Although scientific authenticity may be difficult to achieve in school science, students can gain access to authentic science experiences through programs that enable students to work with practicing scientists. It is our view that students have both personal understandings of NOS and global understandings of NOS and that both can be impacted simultaneously as students participate in science research apprenticeships.

Research Apprenticeships

We use the term research apprenticeship to refer to a broad range of experiences with the following defining characteristics: a learner, a mentor scientist, a professional science context and a focused research project. The learner in this experience may be a secondary student, an undergraduate student, or a preservice or inservice teacher. By mentor scientist we refer to a member of a science research group whose current occupation involves active participation in the practice of science. This mentor scientist may be the principal investigator of a laboratory group or it may be a graduate student, or a post-doctoral associate for example. These research apprenticeships are experiences that are embedded in the context of a working science group. The group will likely maintain a laboratory or field site, and their activities are typically coordinated through a university or a national laboratory (e.g., the Oak Ridge National Laboratory which hosts numerous programs for science teachers and students). Programs that support apprenticeships provide experiences in a variety of science disciplines including biology, chemistry, geology, physics, engineering, and biomedical research (Sadler, Burgin, McKinney, & Ponjuan, 2010). Another defining characteristic of the research apprenticeships model to which we refer is learner involvement in a discernible research project. This research project seeks solutions to an ill-defined question or problem; the results of which hold value to the broader scientific community. For example, a student may be working on a project in which the lab group as a whole is attempting to generate a computer model of the structure of a protein, which has not been previously modeled. This work may eventually go on to be published in a peer-reviewed scientific journal where it is valued by a larger group of scientists. The timing and duration of apprenticeships is another important issue. Although no minimum standard exists to qualify as an apprenticeship program, it is widely recognized that in order for an apprenticeship to be effective, learners need an extended period of time to become a part of a science research community (Ritchie & Rigano, 1996). Literature within science education has documented apprenticeship programs as short as a few weeks to as long as two years. In general, the length of programs is positively associated with the achievement of desired outcomes (Sadler et al., 2010).

Authenticity in Research Apprenticeships

Students can experience varying degrees of authenticity within apprenticeship experiences even within the same program. One way to conceptualize authenticity is in terms of the epistemic involvement experienced by the student. Various components make up our conception of epistemic involvement including the degree to which the apprenticeship participant engages in the formulation of research questions, the selection and/or design of procedures, and the processes of data analysis and interpretation. For example, a student may be involved with his or her laboratory group in the formulation of research questions, the selection and/or design of procedures to be used to investigate those questions, and the analysis and interpretation of the resulting data; whereas, another student working with a different mentor in the same program may be handed a pre-existing research question, given a set of procedures to follow in a step-by-step manner, and have very limited involvement in making meaning of the results of the research. These examples showcase opposing ends of a continuum of epistemic involvement. In most cases, the epistemic involvement experienced by student participants in a research apprenticeship falls somewhere between these two extreme situations. Another way of looking at authenticity is in terms of the nature of the research question itself. Is this question ill-defined and uncertain, or does it have a predetermined and known answer? In cases where the answer may be known, is further supporting evidence of use to the research group? In other words, are the students working on research that has some sort of value to the scientific community? If the answer to this last question is yes, then we believe that students are experiencing an authentic form of scientific practice. From this perspective it would be possible for a student to have very low levels of epistemic involvement (i.e., not being involved with the generation of research questions or methods) yet still be experiencing authentic science. Even with this broad notion of authenticity with respect to apprenticeship experiences, it is possible for students to be engaged in an apprenticeship(-like) program and not have a very authentic scientific experience. For example, a student whose primary responsibility within a laboratory group is to clean glassware does not experience much in the way of authentic science. Unfortunately, we know of students who have had these limited experiences in the context of a research apprenticeship, but in our investigations these very impoverished experiences within apprenticeship programs are exceptions rather than the norms (Burgin, Sadler & Koroly, in review; Sadler et al., 2010).

Teaching NOS Implicitly through Research Apprenticeships

Proponents of research apprenticeships often claim that learner participation in these programs will lead to more sophisticated understandings of NOS. This is based on the notion that by engaging in the process of science, learners will develop more appropriate understandings of how knowledge is developed in authentic contexts of science. In other words, doing science will implicitly result in learning about the epistemology of science. This suggestion is supported by empirical research demonstrating that secondary students involved in extended scientific research with practicing scientists in research apprenticeships develop sophisticated understandings of the tentative nature of scientific knowledge, the creative ways in which it is generated, and the collaborative nature of its development (Richmond & Kurth, 1999). In interviews conducted with high school participants in a 7-week long research apprenticeship, Richmond & Kurth (1999) document that students develop these NOS understandings as they construct identities as scientists. The authors claim that, through a process of enculturation in research apprenticeships, students come to view themselves as working members within a culture of scientific practice and better appreciate the epistemology that guides that practice without explicit instruction on NOS. That being said, it should be noted that these participants were asked to reflect in journals on their views of science. The extent to which these opportunities for reflection impacted student NOS conceptions remains unclear in this research.

Others question the implicit approach to NOS learning in the context of a research apprenticeship. Bell and colleagues (2003) systematically examined the implicit impact of participation in a research apprenticeship on participants' conceptions of NOS. Using an open-ended questionnaire specifically addressing various NOS aspects both prior to and following secondary student participation in an 8-week long research apprenticeship, the researchers found that most participants' NOS conceptions remained unchanged (Bell, Blair, Crawford, & Lederman, 2003). 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 this study, it was observed that one student showed gains in understandings of the creative aspect of NOS. The authors attribute this gain specifically to the epistemic demand placed on 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. The program employed an implicit model of NOS instruction, but in the case of the single student who showed gains, the authors document ways in which she experienced a more personalized explicit approach.

The role the mentor plays in providing a reflective atmosphere for considering issues of science epistemology may play an even more significant role than the epistemic involvement on the part of the participant. In our own research examining the impact of a research apprenticeship employing an implicit approach to NOS instruction on secondary students conceptions of NOS, we documented that student participants exited a research apprenticeship program with a variety of understandings regarding the tentativeness, creative, and social aspects of NOS (Burgin et al., in review). A common feature of the experience of the research apprenticeship for those students that left with sophisticated NOS understandings was the personal interest they had in their specific research project and a high level of collaboration within their research groups. It is interesting to note that epistemic involvement did not seem to be a contributing factor to the development of these NOS understandings. In fact, one student who experienced limited levels of epistemic involvement in the formulation of a research question and the design of investigative procedures, developed sophisticated NOS perspectives as a result of explicit conversations with his mentor about why his epistemic involvement was necessarily limited. Such findings seem to lend less support to the idea that participation in a research apprenticeship can impact NOS understandings even under implicit instructional conditions.

Teaching NOS Explicitly through Research Apprenticeships

Although implicit approaches for teaching NOS are the dominant model for research apprenticeships, at least as reported across the literature (Sadler et al., 2010), some apprenticeship programs have adopted more explicit approaches. For example, Charney and colleagues (2007) studied a four-week apprenticeship program for high school students. The mentor scientists involved in this work modeled their own reasoning practices and consistently posed questions that demanded critical reflection on NOS constructs through a series of seminars. Students kept journals in which they responded to reflective prompts on a near daily basis. Students completed an open-ended NOS questionnaire before and after the experience as a means of assessing potential NOS gains. Results indicated that most students' conceptions of NOS shifted towards more sophisticated understandings of the tentative nature of scientific knowledge. The authors attribute this shift to the to the explicit/reflective nature of the program itself.

A similar result is found by others investigating the impact of an explicit/reflective approach to NOS learning on preservice teachers participating in a research apprenticeship (Schwartz, Lederman, & Crawford, 2004). In this study, 11 of 13 participants showed gains in NOS understandings based on pre and post responses to an open-ended questionnaire and follow up interviews. All of these participating preservice teachers were able to link their NOS understandings to their specific research experiences. The authors suggest that these changes 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. It is also worth mentioning that the preservice teachers who were most able to reflect in this study were those that viewed themselves as outsiders looking in to the practice of science during the process of reflection. This is noteworthy in that it seems to suggest that the process of enculturation into the practice of science and subsequent identity formation as a scientist may actually hinder the reflective process. In contrast to this perspective, Richmond and Kurth (1999) document increased conceptions of NOS when participants in research apprenticeships view themselves as insiders in working science labs. We agree with this latter perspective and believe that a desirable feature of research apprenticeships is the degree which participants can view themselves as working members within a culture of practice. Such a transition from outside to inside the practice of science actually supports notions of reflection in the midst of practice as opposed to reflection on past experiences (Schön, 1983; 1987).

DISCUSSION

What does this literature base tell us about NOS and research apprenticeships? First, we think it gives us good reason to believe that research apprenticeships can serve as productive contexts for reflection on various NOS aspects. The empirical research supports a wide variety of desired experiential aspects of research apprenticeship programs. Among these are epistemic involvement on the part of the apprentice, a collaborative environment, individual interest in the research project and a supporting mentor (Burgin et al., in review). However, we recognize that even within the same research apprenticeship programs individuals can experience each of these aspects in varying ways depending on the specific context of their laboratory placement. In other words, some participants in research apprenticeships may have extremely desirable experiences whereas others may be participating in "worst-case" scenarios. For this reason, we believe that programmatic aspects that emphasize an explicit/reflective approach outside of the individual research laboratories may be influential in impacting all student participants' conceptions of NOS. For example, when an explicit/reflective approach to NOS is utilized, even apprenticeship participants who are experiencing limited epistemic involvement may still develop appropriate NOS understandings. In fact, most of the preservice teacher participants of the Schwartz et al. (2004) study experienced a low level of epistemic involvement in their research apprenticeship. These preservice teachers were given pre-determined procedures to follow and made no decisions regarding the design of their study. However, when immersed in an explicit/reflective approach to their apprenticeship, these teachers showed significant development in their NOS understandings. It seems to follow that regardless of the individual experience, a research apprenticeship has the potential to provide an excellent context for reflecting on NOS and that the process of explicit reflection may lead to increases in NOS conceptions even in less then desirable individual experiences within research apprenticeship programs.

We also think that research apprenticeships can bridge the gap that some claim exists between students' personal and global views of NOS (Hogan, 2000; Sandoval, 2005). In typical school science, a learner's personal experiences with science is significantly removed from the activities of practicing scientists (Brown et al., 1989). It is not surprising that these experiences tend not to support development of desired, global NOS views. Apprenticeships offer learners opportunities to experience science in ways that are more consistent with the ways that science is practiced by working scientists. It is in this context that we predict a convergence of students' personal and global views of NOS. In fact, authentic research apprenticeships may provide the contexts that make distinctions between global and personal epistemologies of science irrelevant.

If these research apprenticeships do cross the divide between personal and global epistemologies then perhaps new methods for assessing NOS in these contexts are warranted. Much of the research on the influence of research apprenticeships on NOS understandings utilizes assessments that are measuring student conceptions of professional science. They ask questions about the big picture of science. These assessments talk about scientists as if they are a distant group of professionals that students may know about but not necessarily feel like they are a part of. We suggest that value exists in assessing students' views of their own practice of science. Perhaps assessments can be created that examine both personal and global epistemologies simultaneously. For example, prompts on existing NOS questionnaires could be modified in ways that require students to situate their responses in the context of their own personal experiences within their research apprenticeships. We believe that such explicit connections should be made on the instruments themselves and not just during follow-up interviews.

Proposed Research Agenda

Based on our examination of the empirical science education literature regarding research apprenticeships we think that a great deal of research remains to be completed in order to extend a currently limited research base that explores the impact of these experiences on participant NOS conceptions (Sadler, et al., 2010). What follows is a list of potential avenues of research in need of further explicit attention.

-*Comparison of formal/practical epistemologies of science held by students and their mentors*: Not a lot of work has been done that compares the NOS views of students and their mentors.

-*Examination of the significance of having a mentor with informed NOS perspectives as opposed to having a mentor with naïve understandings of NOS:* Do students with informed mentors leave research apprenticeships with more informed conceptions?

-*Comparison of explicit/reflective versus implicit approaches to the development of NOS understandings of secondary student participants in a research apprenticeship:* Khishfe and Abd-El-Khalick (2002) systematically examined this relationship in the context of a traditional secondary science classroom, but research like this has yet to be explored in the context of a research apprenticeship.

-*Investigation of the authenticity of a research apprenticeship experience on the development of NOS understandings:* Perhaps a comparison of the explicit/reflective versus implicit approach in the context of a research apprenticeship may yield entirely different results than those observed by Khishfe and Abd-El-Khalick (2002) in a more traditional setting. If so, is this due to the greater levels of authenticity in a research apprenticeship? Are there varying degrees of authenticity?

-*Development of an NOS assessment instrument specifically written for the context of a research apprenticeship:* NOS questionnaires have been developed for a variety of different audiences (Lederman et al., 2002; Schwartz & Lederman, 2008) including students, teachers, and scientists, but none have been developed specifically for participants in a research apprenticeship. Such an instrument should take into account both personal and global view of NOS and may provide evidence that research apprenticeships are contexts that provide links between these two perspectives.

-*Rich ethnographic accounts of apprenticeship experiences with particular attention paid to conceptions of NOS:* More work is needed that is based on detailed observational descriptions of the underlying epistemologies present in individual research apprenticeship settings. Do experiential differences or discipline difference matter? What are the implications for the design of research apprenticeships and the selection of participating laboratory research group hosts? Ethnographic research may shed some light on these questions.

CONCLUSION

This work outlines a theoretical perspective of these experiences that may bring together the personal and global NOS perspectives held by participants in research apprenticeship programs. Such a perspective may change the ways we think about the implicit impacts that these programs may have on NOS conceptions as well as the ways in which we assess these perspectives. There are very few research studies that focus explicitly on the impact of participation in research apprenticeship programs on learners' conceptions of NOS. We hope that a thoughtful consideration of this proposed research agenda will result in an expanded empirical literature base that can be used to help guide the development and implementation of future research apprenticeship programs.

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