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University Science Students' Epistemological Orientations and Nature of Science Indicators: How Do They Relate?

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ABSTRACT *Recent science teaching standards advocate for broad public understanding of the nature of science and for promoting activities that encourage people to critically discuss scientific theories, weigh conflicting evidence, and practice "thinking" like scientists (National Science Education Standards, 1996; Science for All Americans, 1994). For these standards to be effective, however, people must have an understanding of science that allows them to view knowledge as contested and incomplete. In essence, these standards establish the need for a complex epistemology of science. In this qualitative analysis, we examine the relationship between college students' epistemological orientations in the sciences and indicators of behaviors that denote an understanding of the nature of science. We then discuss the implications of this relationship for theory building in both domains.*

KEY WORDS: *Epistemology, nature of science, personal epistemology, science standards, domain specific epistemology*

Introduction

Recent science teaching standards advocate for an understanding of the nature of science among students and in the general public. These standards, particularly those focused on scientific literacy and understanding the "nature of science," promote activities that encourage people to critically discuss scientific theories, weigh conflicting evidence, and practice "thinking" like scientists (*National Science Education Standards,* 1996; *Science for All Americans,* 1994). For these standards to be effective, however, people must have an understanding of science that allows them to view knowledge as tentative. That is, knowledge in science is incomplete, but one can make meaningful distinctions among competing truth claims based upon evidence, logic, and social context. In essence, these science teaching standards establish the need for a complex epistemology of science.

As science educators attempt to facilitate more complex understandings of science and better science literacy, the underlying epistemological beliefs of students, teachers, and learning processes come to the forefront. Epistemology is the study of how one understands what knowledge is and how that understanding or set of beliefs impacts one's actions during teaching and learning. Theorists and researchers describe epistemological development as a pattern of cognitive development that progresses from simple, right-wrong thinking, through an exploration of multiple perspectives, to an understanding of knowledge and knowing that uses contextual and reasoned thinking (Hofer & Pintrich, 1997). Underlying this gradual development in thinking is a dramatic change in students' epistemology from a view of knowledge as a collection of known facts to a perspective that sees knowledge as contextual and evolving. Students, who view knowledge in black and white terms, thus espousing relatively unsophisticated epistemologies, may tend to adopt simplistic learning strategies, such as rote memorization, for learning science. Students with complex epistemologies may be better able to view science learning as a process, continually evolving, and building upon previous knowledge (Edmondson & Novak, 1993). Likewise, instructors who present science in a positivist fashion, emphasizing "objective" observation of phenomenon divorced from pre-existing understandings or from other relevant contexts, reinforce simplistic learning strategies and epistemological beliefs. In contrast, instructors who teach science as ongoing knowledge construction promote a critical perspective, which views scientific knowledge as evolving and implicitly connected to theoretical orientations (Hashweh, 1996; Kelly, Chin & Prothero, 2000; Windschitl & Andre, 1998).

Literature on personal epistemology from theorists and researchers in educational psychology and higher education can complement and extend work in science education that explores how students and teachers understand the nature of science (NOS). In a prior study focused on developing a grounded theory of cross-domain epistemological development, the authors found that individual college students' epistemological orientations in the sciences may vary significantly from their epistemologies in other domains (Palmer & Marra, 2004). In the current study, we apply a qualitative analysis of student interviews to look for evidence of a relationship between students' science epistemological orientations and behaviors that denote their views on the nature of science. Although this link seems intuitively logical, this analysis offers data to empirically test this relationship and discusses the implications for both domains.

Review of Relevant Theory and Research

In conceptualizing this research, we explored theory and research from the domains of epistemological development and beliefs, as well as the literature and research on students' and teachers' understanding of the nature of science.

Epistemological Development

This study draws upon the theory of intellectual or epistemological development advanced by William Perry (1970) as well as other theorists who have examined the cognitive development of college students (Baxter-Magolda, 1992; Belenky, Clinchy, Goldberger & Tarule, 1986; King & Kitchener, 1994). These theorists suggest a common pattern of cognitive development that progresses from simple, right-wrong thinking, through an exploration of multiple perspectives, to an understanding of knowledge and knowing that uses contextual and reasoned thinking. Underlying this gradual development in thinking is a dramatic change in students' epistemology from a view of knowledge as a collection of known facts to a perspective that sees knowledge as contextual and evolving. For example, the model of epistemological reflection, as described by Baxter-Magolda (1992), describes a representative view of epistemological development that progresses through the following stages[1]:

- Absolute knowing: knowledge is certain and obtained from authorities (receiving, then mastery through practice)
- Transitional knowing: knowledge is partially certain and requires understanding (interpersonal resolving of ideas or impersonal - using logic, debate, research)
- Independent knowing: knowledge is uncertain and requires independent thinking (inter-individual [open-mindedness] or individual challenging)
- Contextual knowing: knowledge is contextual, based on evidence in context. Early research on college student epistemology focused on developing, verifying and extending theories of cognitive development (Allen, 1981; Baxter-Magolda, 1992; Baxter Magolda, 1993; Hofer, 2000; Kitchener, Lynch, Fischer, & Wood, 1993; Luttrell, 1989; Moore, 1989; Perry, 1970).

The research emerging from this theoretical orientation is shaped by its *developmental* focus and contrasts it from investigations on epistemological *beliefs* — which seeks to identify categories of beliefs, such as externally controlled learning, simple knowledge, quick learning, and certain knowledge (Schommer, 1993, 1994; Schommer, Crouse, & Rhodes, 1992). In this theoretical frame, an individual's beliefs about knowledge are measured as a complex set of beliefs that are interrelated yet conceptually separate. Additionally, the theory of epistemological beliefs does not posit a developmental trajectory.

Attaining a complex epistemology is considered a desirable outcome of higher education; however, multiple research projects conducted at several universities have found that first-year college students most frequently are rated as indicating a multiplist orientation to knowledge (Eaton, McKinney, Trimble, & Andrieu-Parker, 1995; Marra, Palmer, & Litzinger, 2000; Pavelich & Moore, 1993). These students recognize that multiple points of view may exist, but generally attribute this to shortcomings in authority rather than an understanding that these multiple perspectives could each be valid, depending on the context in which they are applied. For instance, engineering students holding multiplist views while working on an open-ended design project may be disturbed or shocked that neither the client nor the professor has a definite answer to the problem at hand.

Research on epistemological development has been used to explain student behaviors relative to teaching and learning (Angeli, 1999; Schraw, Bendixen, & Dunkle, 2002; Windschitl & Andre, 1998) both as an outcome variable for measuring the impact of instructional interventions (Marra et al., 2000; Valanides & Angeli, 2005), as well as to guide design of instructional activities in order to impact epistemological development (Knefelkamp, 1974; Stephenson & Hunt, 1977; Widick & Simpson, 1978).

More recently, researchers have begun to focus on individuals' epistemological beliefs or development in different disciplinary domains (Hofer, 2000; Jehng,

1. The reader is referred to Hofer and Pintrich (1997) for a review of different theories of epistemological development.

Johnson, & Anderson, 1993; Paulsen & Wells, 1998; Schommer, 1993). The results of this line of inquiry have produced inconsistent findings. In a prior study in which the authors developed a new grounded theory of domain epistemologies (Palmer & Marra, 2004), it was noticed that individual students exhibited different epistemological perspectives in humanities versus scientific knowledge domains. These results are similar to Gallagher (2001), who found in a study of adolescents in grades 9-11 that only 3 of 21 students demonstrated consistent epistemological sophistication across ill-structured problems in different domains. Similarly Edmondson and Novak (1993), in their study of students' beliefs about science learning, hint that students exhibited different epistemological beliefs for different domains, but did not expand on this finding.

In contrast, Schommer and Walker's (1995) research on domain dependent epistemologies found that students displayed a consistent level of epistemological sophistication for texts in mathematics and social sciences. The researchers found domain consistency for the majority of students, but failed to report how many students were inconsistent across domains. In a more recent study, researchers reported similar results (Schommer-Aikens, Duell, & Barker, 2001).

Several researchers have explored epistemological orientations within college-level science classrooms (Hammer, 1994; Westby & Samarapungavan, 2001). Hammer (1994) applied an analytic framework to examine how epistemological beliefs may be involved in the process of learning physics. Hammer's qualitative analysis verified earlier studies on novice physics learners that showed their knowledge to be weakly organized and indicated that they used pure formula manipulation. His study revealed, however, that there were substantial differences between novices that could not be explained by a simple lack of content knowledge, and hypothesized that these differences could be accounted for by their epistemological beliefs relative to physics content, the structure of physics, and beliefs about learning physics. Similarly, Westby and Samarapungavan (2001) found that high school and college chemistry students, who were not involved in chemistry labs, described chemistry in less complex epistemic ways than did professors, graduate students, and undergraduate research assistants, who were involved in "doing chemistry."

The Nature of Science

In parallel with the theoretical explorations in epistemology, science educators have examined individuals' views of the nature of the scientific endeavor. Science has been described and conceptualized in different ways at different points in time. Early in the 20th century, for example, the epistemology of science was equated closely with the scientific method. More recently, descriptions of science as an enterprise have included increased attention to the nature of scientific inquiry and social and cultural factors that may constrain the bounds of acceptable scientific discovery (Abd-El-Khalick & Lederman, 2000).

Several scholars have also attempted to catalogue the essential aspects of the nature of science (NOS). For example, Swartz, Lederman, and Crawford (2004) map the NOS terrain as having the following interdependent elements: tentativeness (science knowledge is open to change), empirical basis (the use of observational methods to produce evidence), subjectivity (science as a human endeavor, filtered through human understanding), creativity (the use of imagination and innovation to produce new knowledge), observation and inference (evidence based upon the interpretation of observations), laws and theories (theories and laws are functionally different types of scientific knowledge), and socio-cultural embeddedness (the values of society determine how science is practiced, interpreted and utilized). Additional elements of NOS include the historical nature of scientific discovery, the public nature of shared scientific discourse, the value of skepticism within the scientific community, and the probabilistic aspects of scientific predictions (Abd-El-Khalick & Lederman, 2000).

The AAS science standards (*Science for All Americans*, 1994) emphasize the following components in their standards for NOS content: an orientation that views the world as understandable, yet also explores the limitations of scientific knowledge for answering human questions; a focus on the logical and empirical, yet subjective, nature of scientific inquiry; the influence of social and political factors on the scientific community. Thus, the various elements of the NOS are intertwined and encapsulate the nature of the knowledge produced by science, the process of producing that knowledge, the context in which the knowledge is produced, and the accepted processes for disputing divergent claims.

A lengthy line of inquiry has investigated the NOS-related beliefs and practices of science teachers. In many cases, these findings have indicated that K-12 science teachers expressed limited conceptions of the NOS, or more frequently, used instructional methods that conveyed a limited conception to their learners (Lederman, 1992). Interventions designed to systematically facilitate more complex beliefs about the NOS among pre-service teachers have met with limited success (Abd-El-Khalick & Lederman, 2000). In an examination of NOS beliefs among college professors, Southerland, Gess-Newsome, and Johnston (2003) found that professors may personally express very sophisticated beliefs about the NOS, but that these beliefs are nuanced by their own disciplinary experiences and may not translate directly into instructional practices.

The bulk of the research on students' conceptions of the NOS has been conducted with elementary and secondary students and has generally found that students expressed naively absolutist views of science (Lederman, 1992). Recently, in an in-depth qualitative study of five secondary science students, Moss, Abrams, and Robb (2001) noted that by the end of the academic year, students had achieved a complex view of the NOS on several dimensions within their model. In this study, students were more likely to express a more complete conception of the nature of scientific *knowledge* than of the nature of the scientific *enterprise*. Studies examining students' beliefs about the NOS have been confounded by measurement issues and by lack of conceptual clarity about what constitutes a complex view of the nature of science. Indeed, the study of students' beliefs about NOS may be further confounded by cross-cultural differences (Sutherland & Dennick, 2002).

Recent research on tertiary students' views of the nature of science has not found profoundly different results from investigations of secondary science students. Several studies reported that university students hold essentially positivist views of NOS (Edmondson & Novak, 1993; Ryder, Leach & Driver, 1999; Valanides & Angeli, 2005). While expressing some indication that scientific knowledge is tentative, most students did not express a view that science knowledge is developed.

Purpose

The purpose of this study is to create an evidence-based bridge between the theory and research on university students' epistemological development in sciences and the theory and research on students' beliefs about the NOS. While these two lines of inquiry seem to be intuitively linked, we sought to provide specific data-driven evidence to confirm or disconfirm this connection. Next, we describe the methodological background for the qualitative data analyzed for this investigation.

Methods

The data for this investigation originates from verbatim transcripts of interviews with 47 junior and senior college students majoring in the sciences and engineering at a large eastern university in the United States. Of the 47 students, there were 14 women (30%) and 33 (70%) men. There were no underrepresented minorities. When the interviews occurred, 29 students were first-semester juniors and 18 were second-semester seniors. The cumulative GPA just prior to being interviewed ranged from 2.00 to 3.98 (on a 4.0 scale), with an average GPA of 3.13.

The interviews for this study were purposefully sampled from a larger set of student interviews. The 47 student interviews met the following criteria: the student was a junior or senior, the student was a science or engineering major, and interview had content that provided evidence of the student's epistemological beliefs about the sciences. We focused the analysis on juniors and seniors, as our experience shows that students with more advanced class standings and, thus, more course experiences have more to say regarding their beliefs about knowledge and learning in the sciences.

To gather the original interview data, researchers contacted students by phone and asked them to participate in a semi-structured, in-person interview about their academic experiences. Six interviewers were trained by an expert[2] in eliciting epistemological development data using mock interviews and videotaped simulations. The interview protocol was based on one used in previous studies of intellectual development (Pavelich & Moore, 1996) and was designed to ascertain students' epistemological views. Interviewers asked students their views on what stood out to them in college so far, about their definition of the ideal college education, their preferences for learning, their definitions of knowledge and truth, how they solved open-ended problems, how they made decisions in the face of conflicting information, their experience as learners in science and engineering courses as compared to humanities courses, and their encounters with people who held views different from themselves. All interviews were transcribed verbatim and imported into NVIVO for coding by the authors.

The current analysis examines the relationship between science-specific epistemologies and behaviors that reflect the science standards pertaining to understanding the NOS. The initial coding focused on the first aspect — science-specific

2. The expert was from the Center for the Study of Intellectual Development in Olympia, WA, USA.

epistemologies. In a multi-phased coding of these data that examined students' comments on their learning in science courses[3], the authors found three emergent orientations that represented students' epistemologies in the sciences. We labeled these categories as Science I (least complex), Science II, and Science III (most complex). Figure 1 depicts these orientations. Students in science orientation I see "science as fact" and understand the discipline as a collection of true and accurate facts. Individuals in science orientation II, "science as theory or theory or fact with exceptions," begin to understand that science is not simply a collection of facts but also includes theories that have varying amounts and sources of evidence. In science orientation III, students perceive science as a collection of pieces of evidence within theories. Persons in this orientation view science as evolving, but also understand that this evolution is more than just multiple opinions. Multi-phased interrater consistency checks produced 54% and 78% agreement rates with all differences subsequently resolved. For further details on this coding phase refer to Palmer and Marra (2004).

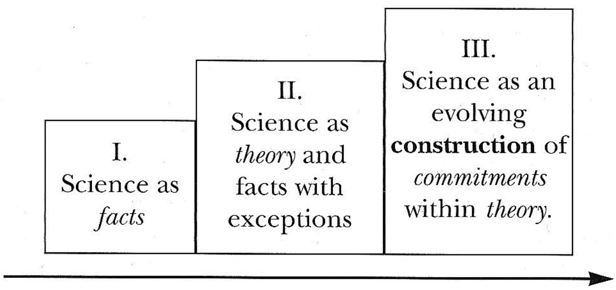

Figure 1. Epistemological Orientations for Science

We then conducted a second coding to look for interview evidence of the three behaviors we defined as indicators of a sophisticated understanding of the NOS: critically discussing scientific theories, an understanding of how to weigh conflicting evidence and thinking like a scientist. We used the following specific behaviors gleaned from our reading of the NCES and AAAS (American Association for the Advancement of Science) standards (*National Science Education Standards,* 1996; *Science for All Americans,* 1994) to code the interviews for evidence of the three indicators. We list each behavior followed by the types of utterances that constituted evidence for each.

1. Critically discussing scientific theories:
   - Questioning truth or accuracy of theories;
   - Discussing the nature of theories as being changeable or impermanent;
   - Discussing or evidence of knowledge that scientific theories have been disproved in the past (NSTA, 2000).

3. Note that in all cases, "science" refers to courses in physics, chemistry, biological and physical sciences, engineering and mathematics.

2. Weighing conflicting evidence (in the context of science):
   - Discussion of a process that is based on the strength of evidence, sources of evidence and/or congruity of evidence with prior research or theory for examining conflicting points of view and/or making decisions (Driver, Newton, & Osborne, 2000).
   - Discussion of the use of evidence in making a decision for what is right or what to believe.

3. Thinking like a scientist:
   - Discussion of evidence concerning the ability to consistently review and adjust scientific models (Garratt, 1998)
   - Discussion of the role of the scientist as that of continually gathering evidence, reviewing evidence relative to current theory, proposing or building new theories, or modifying existing theories or models.

Midway through the coding process, we met to discuss our individual coding of the three indicators and to check that we were applying the coding guidelines or behaviors consistently. To perform this check, the authors both coded the same subsections of the 47 student interviews. This consistency check for the 47 interviews showed an interrater consistency of 89%. We then completed our coding of the interviews for the indicators.

Results

All 47 student interviews (100% of our sample) were ratable for both NOS indicators and science epistemology. We categorized the students for their science epistemologies using the orientations defined in Figure 1. The results of our analysis showed that 17 (36.2%) students described their understanding of science in simple, dualistic terms (orientation I). Another nine students (19.1%) described science as fact, but expressed some understanding that there might be exceptions to the hard and fast rules that they perceived as being associated with science. These students were categorized as being in transition between orientations I and II. Ten other students (21.3%) expressed a view of science as multiple theories or theories with exceptions – orientation II as described above. Of the remaining eleven, only one student demonstrated a truly complex epistemological view of science (orientation III), where one understands science knowledge as contextual and evolving. The other ten students were approaching this complex understanding of science and demonstrated a contextual epistemological position that was not yet fully developed (Orientation II – III). Table 1 presents students quotations that represent each of these orientations.

For the NOS indicators, seven students (14.9%) clearly described all three NOS behaviors during their interviews. Another 19 students (40.4%) described two of the three behaviors and 18 students (38.3%) mentioned one of them. In three interviews (6.4%), we could find no evidence of discussing scientific theories, weighing conflicting evidence, or thinking like a scientist. Quotations from students which illustrate each of the three NOS behaviors are presented in Table 2.

Table 1
Science-specific Epistemological Orientation Sample Quotations

Epistemological Orientation in Science	**Student Quotation**
Orientation I (Science as Fact)	"The truth is always going to be fact to me. It's always going to be. That's what it is. That's it. But, in the science course everything is proven. Like they take you from here and they prove everything. And there's your answer."
Orientation II (Multiple Theories)	"I think in science courses things are based on facts, numbers. But actually my perception of that has changed. The equations that you see in . . . [the] physics book just simply don't apply in the lab. And it will take that many pages just to describe a few circuit elements and it doesn't even cover all the anomalies."
Orientation III (Science as an evolving *construction* of *commitments* within *theory)*	"Science is all approximations and guesses and simplifications. Big thing in fluid mechanics is aerodynamics equations. This is the big set of 1, 2, 3, 4, 5 ,6 equations you've got to solve all at the same time to figure out the aerodynamics table. People can solve these equations using computers, but nobody gets the right answer when they solve it. This is the *best* set of equations we have and they are just not right."

Table 2
NOS Indicator Sample Quotations

NOS Indicator	**Student Quotation**
Discussing Scientific Theories	"There's such a long rigorous steps before things are proven from theory to fact. ...you have to prove it and then you have to prove that nothing else can explain it . . . there are experts out there who can disagree and have different ideas on the whole thing and still like you know arrive at the right answer maybe somewhere in between or maybe one or the other."
Weighing Conflicting Evidence	"Research. Maybe find some creditable sources and see what they have to say about it. See if they agree or disagree and get a pool of them and see where the majority is leaning towards . . . "
Thinking Like a Scientist	"But usually in the field, like two people come up with something at the same time but looking at it in different ways. You both continue your research or your work and then, you just kind of see how both of them progress . . ."

Table 3 shows the proportion of students in each orientation who provided evidence of zero, one, two, or three NOS indicators. From Table 3, we can see a weak[4] but positive relationship between science epistemology rating and number of NOS indicators. This relationship is illustrated graphically in Figure 2. Students evidencing less complex science epistemological orientations (e.g., science epistemology orientation I or I-II) were also less likely to describe all three NOS indica-

4 We describe the relationship as "weak" because the pattern of students with lower science epistemological orientations exhibiting fewer NOS behaviors is not as clear in the science epistemology I-II, and II categories.

tors. This pattern is most evident when one examines the proportion of students in each science epistemology orientation (e.g., I, I-II) that evidenced the most NOS behaviors. For example, the three students in our sample who described no NOS behaviors were all rated in science epistemology orientation I, accounting for 17.6% of the students in this orientation. Eighty-two percent of the science orientation I students described either one or two NOS behaviors. Further, none of the science epistemology orientation I students were rated as displaying all three NOS behaviors.

Table 3
The Proportion of Students Describing NOS Indicator Behaviors within Science Epistemological Orientations

	Number of NOS (Nature of Science) Indicators				
Science Epistemology:	Zero	One	Two	Three	Total
Orientation I	3 17.6%	7 41.2%	7 41.2%	0 0%	N=17 100%
Orientation I-II	0 0%	3 33.3%	5 55.6%	1 11.1%	N=9 100%
Orientation II	0 0%	4 40%	2 20%	4 40%	N=10 100%
Orientation II-III	0 0%	4 40%	5 50%	1 10%	N=10 100%
Orientation III	0 0%	0 0%	0 0%	1 100%	N=1 100%

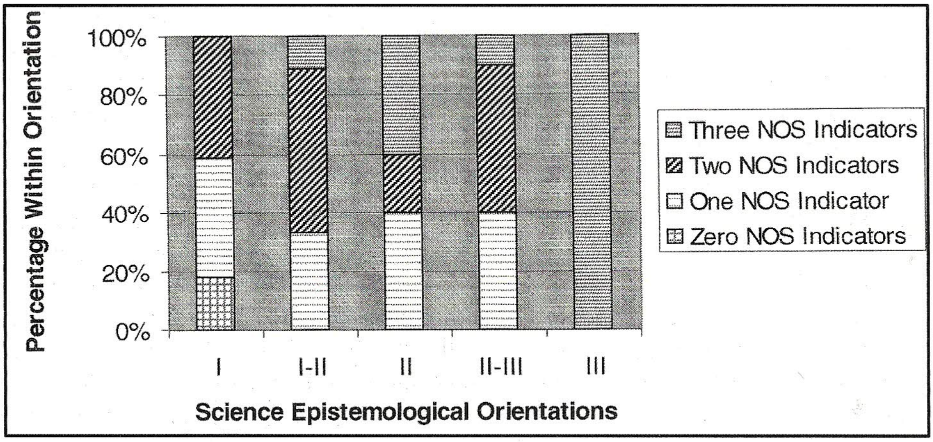

Figure 2. Intersection of Science Epistemology and NOS Indicators

In contrast, the students who clearly demonstrated the most complex epistemological orientation (orientation III) also described all three NOS behaviors. Students in the middle orientations demonstrated varying levels of NOS behaviors.

For example, 40% of the students who fell squarely into science epistemology II described one NOS behavior, 20% described two, and another 40% described three. In spite of the small sample, a trend correlating complexity of epistemology with increased NOS behaviors appears to be supported by the data.

Discussion

We begin our discussion of these results by further examining the relationship between NOS and science epistemology through a comparison of the construct definitions and illustrative student quotations. We then examine the limits of the current work and implications for future theory building and practice.

The Relationship between NOS and Science Epistemology

Our results indicate a weak but qualitatively discernable relationship between NOS indicators and science-specific epistemological orientations for our sample[5]. Generally, students who exhibited less complex epistemologies also exhibited relatively fewer of the NOS indicators as a proportion of total students at that science orientation as indicated in Table 3. Perhaps even more relevant, the portion of our sample at the higher science epistemology orientations (II, II-III and III) exhibited, as a proportion of the number of students in those orientations, more NOS indicators as shown in Figure 2.

The existence of a relationship between these two constructs that seem intuitively parallel is most logically tied up in both the definitions of these constructs, and, further, in the way they are operationalized in classrooms and research settings. Epistemology has been defined as the study of individual's beliefs about knowing and the nature of knowledge. The NOS does not have one commonly accepted definition; however, recent work from Schwartz et al. (2004) provides a description of the components of the NOS. These components—which include tentativeness, empirical basis, and subjectivity—are all descriptors of the nature of scientific knowledge. For instance, scientific knowledge is described as both tentative (changing) and in part, at least, as empirically derived.

Both constructs are concerned with knowledge, and one might say that one aspect of NOS is the epistemology of science knowledge. However, certain aspects of NOS, although related to scientific knowledge, are focused on understanding the unique process of producing scientific knowledge, the role of the producer (scientist), the influence of the community of scientists, and the influence of societal context on knowledge production. This focus on the collective process of knowing within a disciplinary community creates a subtle yet important distinction between NOS and the more uniquely individualistic process of knowing that is the traditional focus of research on personal epistemology. Clearly, personal epistemologies are connected to an individual's understanding of the process of knowing within the scientific knowledge community, but they are not necessarily the same as NOS.

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5 The lack of a larger sample and the less clear distribution of subjects in orientation I-II across the NOS behaviors makes it inappropriate for us to propose a definitive relationship from the current sample.

Figure 3 illustrates this proposed relationship between NOS and science epistemology. Science epistemology is pictured as being a domain-specific example of the overall field of personal epistemology. NOS and science epistemology both address the nature of scientific knowledge, though science epistemology is focused on a *personal* understanding of scientific knowledge whereas NOS includes the broader issues of how scientific knowledge is produced by the activities of scientists.

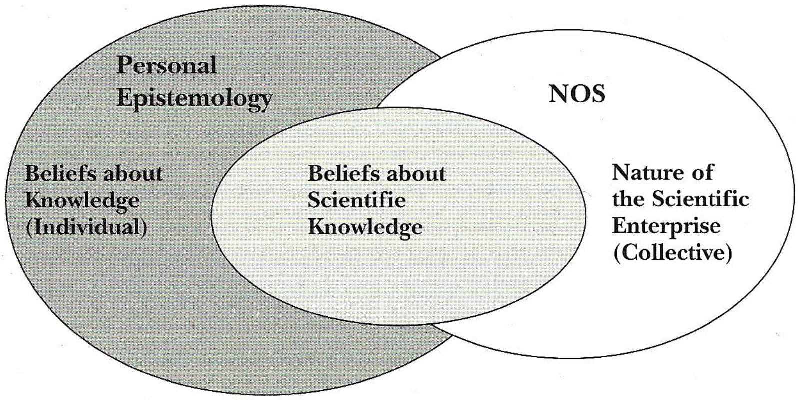

Figure 3. The Intersection of Personal Epistemology in Science and NOS Beliefs

Quotations from our student sample can help illustrate the relationship in Figure 3. For instance, a student's comments about weighing evidence and making decisions illustrate the overlap between the two constructs.

> *Whoever's more credible to me and whoever presents the most overwhelming and persuasive argument wins I guess. Well not only in my mind, but I guess in the scientific arena.*

These remarks show that the student is considering both his personal epistemology ("... more credible to me...") as evidenced in the domain of science, as well as the collective process of knowing in the "scientific arena." In contrast, another student discusses his personal epistemology, so that we realize that his personal way of understanding knowledge and thinking is not necessarily the same as the external processes used in the scientific community to generate a body of scientific knowledge.

> *As an engineer you really have to think for yourself. And it's the thought process that makes engineering what it is in my opinion. And we need, I need a professor, I think in an ideal classroom, who can structure the classes and his lectures to make you think.*

Lastly, another student's quotation is an example of a student discussing just her understanding of the process of scientific knowing.

> *Being an expert is pretty much knowing inside and out what your job is, what your field entails, and basically how it affects ... a zillion people or how it affects numerous people. How it relates to the outside world. But at the same time, having that technical knowledge or whatever kind of knowledge you need to perform.*

Her comments show that she is aware of the social embeddedness of scientific knowledge and activities ("... how it affects numerous people..."), but she does not describe how this relates to her personal understanding of scientific knowledge.

Figure 3 illustrates a conceptual understanding of the relationship between science epistemology and NOS based on these illustrative student quotations and the intersection of ratings between science epistemology and NOS (e.g., Table 3) data. Taken together, Figures 2 and 3 describe a relationship between science epistemology and NOS that includes *some* overlap – but clearly illustrates that the two constructs are not the same. The limited overlap between the two constructs as illustrated if Figure 3 provide an explanation for the lack of a completely consistent pattern between the two constructs in our data set. If indeed the constructs are only partially the same, we would not expect to see a perfectly predictable relationship.

With respect to the patterns we do observe, there are plausible explanations. For instance, for the students who evidenced less complex epistemological orientations (e.g., orientation I or I-II) and were also less likely to describe all three science literacy behaviors, it may be that a less sophisticated personal epistemology gives way to a similar less sophisticated understanding of the processes that create collective knowledge in the scientific community (NOS). Likewise, the single student in science epistemological orientation III necessarily exhibited an understanding of science as an evolving set of commitments embedded in scientific theory (see Figure 1). Intuitively, such a student is more likely to understand scientific activities that illustrate the NOS in a more sophisticated way. The patterns between science epistemological orientations the exhibiting of one or two NOS behaviors are less clear — especially for those in science orientations I-II and II. We will further explore the intersection of these two constructs – including possible reasons for the lack of clarity in the pattern between science orientations I-II and II and the frequency of NOS behaviors — in the implications section below.

Limitations

Before turning to the implications of these findings for theory building and practice, we review the potential limitations of our results. One limitation of our study concerns the interview protocol and its ability to detect evidence of NOS behaviors. The protocol included many questions on topics, such as effective course work and teaching, knowledge, and processes for solving difficult problems — where students could and often did discuss issues that are relevant to the NOS and that included the indicators we coded. However, the protocol did not include specific questions designed to gather data on the students' conceptions of NOS. Having said this, we point out that 44 of the initial 47 (94 %) students we placed in science-specific epistemology orientations showed evidence of at least one NOS behavior.

Another issue concerns the difficulty of validly measuring either of these constructs. Although our science-specific epistemology orientations were generated based on a commonly accepted and applied interview protocol for gathering epistemological development data (Moore, 1989; Pavelich & Moore, 1993), we recognize that validly measuring either of these constructs is problematic. The measurement difficulty originates in both cases from the need for researchers to find <u>external</u> and observable evidence of cognitive processes that are by their nature <u>internal</u> activities.

Further, by engaging students in the data collection activity – a semi-structured interview that includes thought-provoking questions such as "what is knowledge," or "what is the relationship between truth and knowledge"—researchers may actually be influencing students' thought processes that are exactly what researchers are trying to study. William Perry (1981) described this conundrum many years ago as he developed the interview protocol on which our data collection is based, noting that if we want to study student's thinking, then we have to ask them to think!

Regarding the NOS data, in particular students' discourse surrounding their NOS beliefs, may be unduly influenced by the context of the interview environment. Since the bulk of the interview discussed science knowledge in the context of science classrooms, it would not be unreasonable to assume the students' level of NOS indicators might change if we had focused the interviews on, for example, controversial public issues that applied scientific evidence for a solution or asked questions probing more directly about the experience of the student in scientific research settings.

Lastly, we recognize that our measure of NOS looked merely at existence of the indicators and did not attempt to evaluate the quality of the students' understanding. As such, a student who merely mentioned that a particular scientific theory had been disproved would be rated the same way as a student who went into great detail on the process by which theories are developed, tested and accepted by the scientific community, since both would have been rated as describing the NOS indicator of discussing scientific theories. Similarly, we did not quantify how frequently the indicators were mentioned by students in the interview due to problems with attempting to equate proportionate levels of discussions.

Implications

In the results section, we posited that science epistemology and NOS share only *some* commonalities – but are not simply different names for the same construct. Figure 3 illustrates this conceptual understanding of the relationship between science epistemology and NOS. The limited commonalities between the two constructs as illustrated if Figure 3 provide an explanation for the lack of a completely linear or predictable relationship between the two constructs in our data set. The picture of the relationship between science epistemology and NOS is enriched when we examine how researchers and practitioners pedagogically operationalize these constructs in classrooms.

Both NOS and personal epistemology have been the subject of pedagogical interventions designed to impact students' performance and application of these constructs. Although it is beyond the scope of this article to review the extent and impact of these interventions, we can say that the similarities between the constructs and the relationship we posit is borne out, both in the way they have been addressed pedagogically and in the results of the interventions.

For example, educators and researchers have tested both implicit and explicit instructional interventions designed to facilitate more complex understandings of science with limited success (Abd-El-Khalick & Lederman, 2000). Implicit approaches assumed that students' conceptions of science would be positively affected simply by experiencing an inquiry-based approach to science. These efforts had minimal impact on NOS beliefs. Approaches teaming inquiry-based science instruction with direct discussion of NOS or with content on the history of science proved slightly more effective. Schwartz et al. (2004) teamed scientific inquiry in authentic contexts with guided reflection and found indications that this method could improve NOS conceptions for some pre-service teachers.

With respect to epistemology, there is limited but mixed evidence that direct approaches can influence epistemological beliefs. For example, Valanides and Angeli (2005) used a three-group 65 minute treatment that varied the extent and method used to teach students critical thinking skills and measured the impact on epistemological beliefs. The researchers found a significant main effect on student epistemological change. Post-hoc analysis showed that students assigned to the "infusion" strategy where learners had been given time to address a purposefully ambiguous issue *before* receiving instruction had larger epistemological changes than those in the "general" group where instruction was presented deliberately separate from any content. While such results may be encouraging, it is unclear whether such effects are lasting.

The authors saw an initial impact on epistemological development for students in a project-based first year engineering design course as compared to a control group in a separate study (Marra et al., 2000). However, a significant difference in this indirect approach to epistemological development did not recur with the next cohort of first year students, nor did the difference for the original treatment cohort persist through their next year in college. This research was an example of an indirect approach to developing epistemological beliefs; however, similar mixed results have been found in more direct approaches to impacting epistemological development (Knefelkamp, 1974; Pavelich & Moore, 1996; Stephenson & Hunt, 1977).

Thus, for both constructs one sees mixed results in terms of the impact of direct and indirect means of promoting complex thinking, either epistemologically or for NOS. Although researchers and practitioners in the domains acknowledge that simple maturation will not produce the desired changes in how students think about NOS or knowledge in general, neither set of researchers has been able to consistently operationalize effective pedagogies for promoting these changes. Further, the relationship between the two constructs depicted in Figure 3 indicates that progress in developing more complex understanding of NOS may be enhanced by a practitioner understanding of those aspects of NOS overlapping with science epistemology as well as personal epistemology. This understanding may lead to new approaches—or to approaches borrowed from epistemological development research that may in turn further NOS research and practice.

Lastly, we mention a recently emerging area of discussion in the field of epistemological development that may have a parallel line of reasoning concerning NOS. Researchers and practitioners interested in personal epistemology and its impact on learning are not only examining pedagogical interventions to impact epistemological development, but they are also conducting research to determine the epistemological entailments of certain types of learning environments. For instance, Jonassen, Marra and Palmer (2004) proposed that unless students hold relatively sophisticated epistemological views (e.g., contextually relevant or higher), they will not be able to succeed in learning environments demanding that they process multiple and conflicting points of view or solve complex problems that might have more than one "right" answer.

Yerrick, Pederson and Arnason (1998) propose a similar relationship regarding NOS. In a case study analysis of the impact of teacher classroom management strategies on students' abilities to evidence and develop advanced NOS-related learning strategies, they found that students' existing epistemological perspectives could not be separated from how they interacted and participated in classroom learning activities.

In both domains, researchers suggest that learners can benefit from appropriate scaffolding, that is, the instructional environment must acknowledge learners may not hold sophisticated views of NOS or sophisticated epistemological beliefs. Educators must provide activities that initially *support* students in thinking that requires them to stretch their beliefs and practices. Thus, a class where students are ultimately expected to be able to propose their own scientific theory to explain a data set may begin with activities that guide students through several sample data sets and prompt them, through guiding questions, through a theory building process. Just as real-life scaffolds are designed to be temporary, so learners would eventually be expected to perform activities that require sophisticated ways of thinking on their own.

Conclusions

This paper has explored, through the use of qualitative analysis of 47 undergraduate science and engineering students, the relationship between the theoretical concepts of personal epistemology in the sciences and the nature of science beliefs. Our results in this data set show evidence of a positive yet not conclusive relationship between the two constructs. More specifically, students evidencing less complex epistemological orientations (e.g., orientation I or I-II) were also less likely to describe the three NOS indicators that were possible to code. Conversely, the single student evidencing the most complex science epistemological orientation (III) also showed evidence of all three NOS indicators.

One might assume that a relationship exists between these two constructs. Yet the relationship identified in the coding data from this study shown in Figure 2, taken together with quotations from student interviews, point to a useful representation of what the constructs share in common and how they differ from one another as shown in Figure 3. The common ground of examining the nature of scientific knowledge seems intuitive; however, the areas where the constructs are unique may explain the lack of a stronger relationship between the constructs in our data (see Figure 3). Personal epistemology addresses the *personal* understanding of science knowledge, while NOS addresses the external and collective process in the scientific community of creating and validating knowledge in science. Further, unpacking this relationship provides directions for practitioners and researchers as they consider approaching the design of interventions to impact NOS by addressing specifically the personal epistemology and the external scientific community knowledge in separate but complimentary fashions.

NOS and personal epistemologies in science are foundational belief systems impacting both how learners operate in classrooms as well as how graduates interact with and process knowledge in their adult lives. Although more research and analysis is called upon to validate these findings, our initial results showing a positive relationship between these belief systems, yet also clearly differentiating between the two, may allow researchers and practitioners in both domains to advance their efforts.

References

ABD-EL-KHALICK, F., & LEDERMAN, N. G. (2000). Improving science teachers' conceptions of nature of science: A critical review of the literature. *International Journal of Science Education, 22*(7), 665-701.

ALLEN, R. D. (1981). Intellectual development and the understanding of science: Applications of William Perry's theory to science teaching. *Journal of Science College Teaching , 11*, 94-97.

ANGELI, C. M. (1999). Examining the effects of context-free and context-situated instructional strategies on learners' critical thinking. *Dissertation Abstracts International, 60*(5A), 1477.

BAXTER MAGOLDA, M. B. (1992). *Knowing and reasoning in college: Gender related patterns in students' intellectual development.* San Francisco: Jossey-Bass.

BAXTER-MAGOLDA, M. B. (1993, November 4-10, 1993). *The development of contextual knowing in graduate and professional educational settings.* Paper presented at the Annual Meeting of the Association for the Study of Higher Education, Pittsburgh, PA.

BELENKY, M. F., CLINCHY, B. M., GOLDBERGER, N. R., & TARULE, J. M. (1986). *Women's ways of knowing: The development of self, voice and mind.* New York: Basic Books.

DRIVER, R., NEWTON, P., & OSBORNE, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84*(3), 287-312.

EATON, M. D., MCKINNEY, G. R., TRIMBLE, J., & ANDRIEU-PARKER, J. M. (1995). *Portfolio analysis and cognitive development at Fairhaven College* (Technical and Research Report No. 1995-01). Bellingham, WA: Western Washington University.

EDMONDSON, K. M., & NOVAK, J. D. (1993). The interplay of scientific epistemological views, learning strategies, and attitudes of college students. *Journal of Research in Science Teaching, 30*(6), 547-559.

GALLAGHER, L. P. (2001). *Domain dependency in adolescent's epistemological beliefs.* Paper presented at the Annual Meeting of the American Educational Research Association, Seattle, WA.

GARRATT, J. (1998). Inducing people to think. *University Chemistry Education, 2*(8), 29-33.

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

HASHWEH, M. Z. (1996). Effects of science teachers' epistemological beliefs in teaching. *Journal of Research in Science Teaching, 33*(1), 47-63.

HOFER, B. K. (2000). Dimensionality and disciplinary differences in personal epistemology. *Contemporary Educational Psychology, 25*(4), 378-405.

HOFER, B. K., & PINTRICH, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research, 67*(1), 88-140.

JEHNG, J.-C. J., JOHNSON, S. D., & ANDERSON, R. C. (1993). Schooling and students' epistemological beliefs about learning. *Contemporary Educational Psychology, 18*(1), 23-35.

JONASSEN, D. H., MARRA, R. M., & PALMER, B. (2004). Epistemological development: An implicit entailment of constructivist learning environments. In N. M. Seel & S. Dikjstra (Eds.), *Curriculum, plans and processes in instructional design: International perspectives* (pp. 75-88). Mahweh, N. J.: Lawrence Erlbaum.

KELLY, G. J., CHEN, C., & PROTHERO, W. (2000). The epistemological framing of a discipline: Writing science in university oceanography. *Journal of Research in Science Teaching, 37*(7), 691-718.

KING, P. M., & KITCHENER, K. S. (1994). *Developing reflective judgment.* San Francisco, CA: Jossey-Bass.

KITCHENER, K. S., LYNCH, C. L., FISCHER, K. W., & WOOD, P. K. (1993). Developmental range of reflective judgment: The effect of contextual support and practice on developmental stage. *Developmental Psychology, 29*(5), 893-906.

KNEFELKAMP, L. (1974). *Developmental instruction: Fostering intellectual and personal growth in college students.* Unpublished Doctoral dissertation, University of Minnesota, Minneapolis-St. Paul.

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

LUTTRELL, W. (1989). Working-class women's ways of knowing: Effects of gender, race, and class. *Sociology of Education, 62*, 33-46.

MARRA, R., PALMER, B., & LITZINGER, T. (2000). The effects of a first-year engineering design course on student intellectual development as measured by the perry scheme. *Journal of Engineering Education, 89*(1), 39-45.

MOORE, W. S. (1989). The learning environment preferences: Exploring the construct validity of an objective measure of the perry scheme of intellectual development. *Journal of College Student Development, 30*, 504-514.

MOSS, D., ABRAMS, E. D., & ROBB, J. (2001). Examining student conceptions of the nature of science. *International Journal of Science Education, 23*(8), 771-790.

National Science Education Standards. (1996). Washington, DC: National Research Council.

NSTA. (2000). The nature of science: NSTA position statement. Retrieved April 26, 2005, from http://www.nsta.org/positionstatement&psid=22.

PALMER, B., & MARRA, R. M. (2004). College student epistemological perspectives across knowledge domains: A proposed grounded theory. *Higher Education, 37*(3), 311-335.

PAULSEN, M. B., & WELLS, C. T. (1998). Domain differences in the epistemological beliefs of college students. *Research in Higher Education, 39*(4), 365-384.

PAVELICH, M. J., & MOORE, W. S. (1993). *Measuring maturing rates of engineering students using the Perry model.* Paper presented at the Frontiers in Education.

PAVELICH, M. S., & MOORE, W. S. (1996). Measuring the effect of experimental education using the Perry model. *Journal of Engineering Education, 85*(4), 287-292.

PERRY, W. G. (1970). *Intellectual and ethical development in the college years: A scheme.*

New York: Holt, Rinehart & Wiston.

Perry, W. G. (1981). Cognitive and ethical growth: The making of meaning. In A. Chickering & Associates (Eds.), *The Modern American College* (pp. 76-116). San Francisco: Jossey-Bass.

Ryder, J., Leach, J., & Driver, R. (1999). Undergraduate science students' images of science. *Journal of Research in Science Teaching, 36*(2), 201-219.

Schommer-Aikens, M., Duell, O. K., & Barker, S. A. (2001). *Domain generality of epistemological beliefs: It's a matter of degree.* Paper presented at the Annual Meeting of the American Educational Research Association, Seattle, WA.

Schommer, M. (1993). Comparisons of beliefs about the nature of knowledge and learning among postsecondary students. *Research in Higher Education, 34*(3), 355-370.

Schommer, M. (1994). Synthesizing epistemological belief research: Tentative understandings and provocative confusions. *Educational Psychology Review, 6*(2), 293-319.

Schommer, M., Crouse, A., & Rhodes, N. (1992). Epistemological beliefs and mathematical text comprehension: Believing it is simple does not make it so. *Journal of Educational Psychology, 6,* 39-42.

Schommer, M., & Walker, K. (1995). Are epistemological beliefs similar across domains? *Journal of Educational Psychology, 87*(3), 424-432.

Schraw, G., Bendixen, L. D., & Dunkle, M. E. (2002). Development and validation of the epistemic belief inventory (EBI). In B. K. Hofer (Ed.), *Personal epistemology: The psychology of beliefs about knowledge and knowing* (pp. 261-275). Mahwah, NJ: Erlbaum.

Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). *Science Education, 88*(4), 610-645.

Science for All Americans. (1994). New York: Project 2061: American Association for the Advancement of Science.

Southerland, S. A., Gess-Newsome, J., & Johnston, A. (2003). Portraying science in the classroom: The manifestation of scientists' beliefs in classroom practice. *Research in Science Teachinig, 40*(7), 669-691.

Stephenson, B., & Hunt, C. (1977). Intellectual and ethical development: A dualistic curriculum intervention for college students. *Counseling Psychologist, 6,* 39-42.

Sutherland, D., & Dennick, R. (2002). Exploring culture, language and the perception of the nature of science. *International Journal of Science Education, 24*(1), 1-25.

Valanides, N., & Angeli, C. (2005). Effects of instruction on changes in epistemological beliefs. *Contemporary Educational Psychology, 30,* 314-330.

Westby, E., & Samarapungavan, A. (2001). *The relationship between increased methodological knowledge and epistemic beliefs: The role of instrumentation and techniques in chemistry education.* Paper presented at the American Educational Research Association Annual Meeting, Seattle, WA.

Widick, C., & Simpson, D. (1978). Developmental concepts in college instruction.

In C. Parker (Ed.), *Encouraging development in college students* (pp. 25-59). Minneapolis: University of Minnesota Press.

WINDSCHITL, M., & ANDRE, T. (1998). Using computer simulations to enhance conceptual change: The roles of constructivist instruction and student epistemological beliefs. *Journal of Research in Science Teaching, 35*(2), 145-160.

YERRICK, R. K., PEDERSEN, J. E., & ARNASON, J. (1998). "We're just spectators": A case study of science teaching, epistemology, and classroom management. *Science Education, 82*(6), 619-648.