A Comparison of Students' Beliefs about School Science and Professional Science

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Abstract

This study examined how urban high school students' beliefs about the nature of professional science relate to their beliefs about school science. Two aspects of the nature of science were examined: the status of scientific knowledge and the purpose of experimentation. An open-ended questionnaire, Views of the Nature of Science (VNOS), was used to assess students' beliefs about these two aspects of professional science. Upon completion of a modeling activity, groups of students were interviewed about their views of the purpose of the activity, the status of the knowledge they gained, and how their work related to scientists' work. Students' responses to the interview questions were examined in relation to their responses to VNOS. Students saw the purpose of their school activity as similar to scientists' work, but expressed differences between the status of knowledge across the two contexts. These findings are discussed with respect to the coherence of epistemological beliefs, and how epistemologies of science may be best studies

Introduction

For generations, science teaching has relied on methods that train students to follow directions with little connection to doing real science. Students have become accustomed to this method of science instruction, but few develop a deep conceptual understanding of science (National Center for Education Statistics, 2001). National science standards (e.g., NRC, 1996) urge inquiry teaching to help students develop deeper conceptual understanding in science and their ideas about the nature of science (NOS). Inquiry aims to give students control over their own formation of scientific knowledge. Students become responsible for naming the problem that needs investigation, forming a hypothesis, designing a method for testing their hypothesis, carrying out their method, analyzing results, and finally forming conclusions. Inquiry is hard for students, though, not only because they often do not know much about the topics they investigate, but also because their ideas about the nature of science, what it means to do inquiry, appear naïve. Most students leave high school with overly simplistic ideas about the nature and certainty of scientific knowledge and how such knowledge is produced (Driver, Leach, Millar, & Scott, 1996; Lederman, 1992; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). Until recently, most NOS studies have looked almost exclusively at students' beliefs about professional science. Too little is known of students' beliefs about the epistemological aspects of school science and how these beliefs relate to their beliefs about professional science. In this paper we present a study to explicitly compare students' ideas about their own work in school science with their ideas about formal, professional science. This study builds on recent research showing the inconsistency of students' epistemological ideas across contexts (Hammer, 1994;

Leach, Millar, Ryder, & Séré, 2000; Roth & Roychoudhury, 1994; Sandoval & Morrison, 2003). We suppose that the set of beliefs that students' employ during their own inquiry may not necessarily be the same set of beliefs they express when responding to questions about professional science. If so, then these differences have important implications for inquiry-oriented science education reforms.

Background

It is not surprising that students have a difficult time understanding how scientific knowledge is constructed considering the numerous debates around this topic since the days of Aristotle (see Driver et al., 1996). At the same time, it has been argued that philosophical views of science agree on broad aspects of nature of science (Lederman et al., 2002), standards documents are consistent in their goals with respect to nature of science (McComas & Olson, 1998), and professional scientists also seem to share a broad consensus on epistemological concerns (Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). We suggest that two of these consensus aspects are of particular importance to students' conduct of scientific inquiry. The first is the empirical basis of science, specifically that the purpose of experimentation is to make observations to test a proposed explanation or to create a new explanation about a phenomenon. The second is that the status of scientific knowledge is tentative and changes historically. Here we briefly review commonly found student beliefs about these two aspects of the nature of science, noting how studies couched in differing contexts can produce rather different results.

The Purpose of Experimentation

Philosophers and scientists began conducting controlled experiments in the 1660's. Robert Boyle was the first person to use an air-pump as a means to understand the properties of air. The purpose of this experiment and others that followed was to make an explanation about an observed phenomenon. The results from experiments provide evidence to support a theory (Shapin & Schaffer, 1985).

Students' ideas about the purpose of an experiment differ from scientists' and philosophers' ideas. Previous studies have asked students to explain what the purpose of a scientists experiment is, students often say that scientists conduct experiments to gather carefully accumulated evidence to gain flawless knowledge with one correct answer to a question (Carey, Evans, Honda, Jay, & Unger, 1989; Sandoval & Morrison, 2003). When the results of an experiment do not come out as expected students attribute this to human error while using the scientific method (Hogan, 1999; Linn & Songer, 1993).

In a typical science classroom, where students are *not* doing inquiry, students' naïve ideas about the purpose of experimentation are perpetuated because of the nature of the students' tasks. Typically students practice science in a "cookbook" way where they follow the directions of an experiment and get the "right" answer. The goal in this type of experiment is to get the right answer. In a science classroom where students are engaged in inquiry the goal of the experiment in not about getting the right answer, but about investigating and testing out their ideas by manipulating variables. When students are asked to conduct their own inquiry it challenges their beliefs about how science is done and how it is learned (Roth & Roychoudhury, 1994; Smith, Maclin, Houghton, & Hennessey, 2000; Tobin, Tippins, & Hook, 1995).

If we want students to conduct and interpret experiments scientifically, they need to understand the purpose of them. They need to understand that the motivation for an experiment is verification or exploration (Carey et al., 1989). Zimmerman (2000) has reviewed several studies about students' strategies of experimentation. From this research it can be concluded that the goals students pursue affect investigative strategies. For example, students are more systematic in their investigations when the goal is to generate an explanation, rather than verify a given hypothesis (Dunbar, 1993). However, these studies do not illuminate how students perceive the purpose of their own activity, including whether or not they see such work as a particular form of school activity or as a scientific activity.

The Status of Scientific Knowledge

Many researchers and curriculum developers believe that tentativeness is the primary attribute of scientific knowledge (Lederman & O'Malley, 1990). The word "tentativeness" refers not only to recognizing that scientific knowledge has changed throughout history, but understanding that these changes have happened through the use and development of theories. This assertion rubs many the wrong way, as if it implies an inescapable relativism: since scientific knowledge is not known to be absolutely true, then there is no particular reason to believe it. In their recent study, Osborne and colleagues (2003) provide a useful refinement of the tentativeness assertion – some claims are more tentative than others. For all practical purposes, the force of gravity is not a tentative idea; whereas string theory is quite tentative.

Previous research studies have asked students to explain what they think is the status of scientists' knowledge. Students at most age levels understand that scientific knowledge changes, but tend to see change as a “right” idea replacing a “wrong” one. They do not believe that theories as a whole change (Driver et al., 1996; Khishfe & Abd-El-Khalick, 2002; Lederman & O'Malley, 1990; Linn & Songer, 1993). Students do not recognize these changes and view scientific knowledge as unproblematic and providing right answers (Carey et al., 1989; Driver et al., 1996). They believe that getting “right” answer relies on proper employment of the scientific method (Hogan, 1999; Linn & Songer, 1993).

It is understandable that students have these types of beliefs about the status of professional scientists’ knowledge given the typical lecture style learning environment that most students are in. In these types of classrooms there is strictly textbook learning, with the occasional “cookbook” lab. The knowledge that students gain from these classrooms is presented to them as definitive knowledge, which provides students with little to no opportunity for valid alternative conclusions or interpretations of results. This gives students an impression that to every question there is only one answer. Students need to understand that scientists construct scientific knowledge, its status is tentative and its development experiences a series of revolutions (Lederman & O'Malley, 1990).

It seems intuitive that students in an inquiry oriented science classroom would develop a better understanding about the status of scientific knowledge because the way that they gain knowledge is very different from a typical classroom. In an inquiry classroom students are required to construct their own scientific knowledge, share it with the class, and then come to a consensus about the conclusions they are drawing. In this type of environment students are encouraged to have alternative conclusions or interpret results differently. Yet, available evidence suggests that inquiry does not ineluctably lead to sophisticated epistemological understanding (Khishfe & Abd-El-Khalick, 2002; Meichtry, 1992; Sandoval & Morrison, 2003). This may mean that epistemological issues need to become explicit in instruction. More fundamentally, we need to know more about the epistemological ideas that students actually bring to bear during science learning and how they may develop into sophisticated epistemological frameworks (Sandoval, 2003).

Coherence in Students' Beliefs

As reviewed above several studies have examined students' NOS beliefs. Some researchers believe that students' NOS beliefs are coherent, unitary frameworks (Carey et al., 1989; Kuhn, Cheney, & Weinstock, 2000). These studies argue that students have coherent frameworks that become more informed in a stage like way. For example, a student who understands that science is tentative would also understand that the purpose of an experiment is to test ideas. Conversely, a student who did not understand that science is tentative would also not understand that the purpose of an experiment is to test ideas.

Recent evidence suggests that NOS beliefs are fragmented and contextualized (Hammer, 1994; Leach et al., 2000; Roth & Roychoudhury, 1994; Sandoval & Morrison, 2003). These studies show that students' ideas about NOS can be internally inconsistent, even incommensurate. Sandoval and Morrison found, for example, that the same student might believe that the purpose of experiments is to test ideas, but that ideas have no influence on the kind of experiments a scientist might choose to do or how experimental results might be interpreted. Leach and colleagues found that students' expressed ideas seemed more sophisticated when elicited in contexts about which they knew something, rather than general questions about the nature of theory or experimentation. These findings suggest that students' specific epistemological ideas about scientific knowledge and how it is constructed are fragmented or localized beliefs, or epistemological "resources" (Hammer & Elby, 2002), and that science educators need more detailed knowledge about what these ideas are, when they are activated, and how they might be developed into coherent epistemological frameworks.

The Present Study

The present study explored the coherence in students' beliefs about school and professional science. Specifically, we asked two questions. Do students perceive the purpose of their experimentation in school as the same as scientists' experimentation? Do students see the status of their own knowledge, and the sources of knowledge change, as the same as scientists' knowledge? For each question, we were also interested in documenting how students' reason about these two issues in each context.

Method

Participants

A sample of 12 students (5 female, 7 male) from one 10th grade integrated science class participated in the study. Thirty-one students were enrolled in this class, but absences kept many of them from full participation in either the inquiry activity or the interview. These students attended an urban high school located in a mixed-income area of a large city. The students in this sample were African American and Latino. Nine of the students in this sample were in 10th grade, and three students were in 9th grade.

Procedure

At the beginning of the study students completed the Views of Nature of Science Questionnaire (VNOS, Lederman et al., 2002), which assessed their beliefs about professional science. About four months later, at the end of their first semester, students completed a modeling activity about protein synthesis, described below. Once the modeling activity was completed, groups of students were interviewed about their modeling activity. Each student in a group was asked to respond to each interview question, allowing individual scores to be assigned and compared to VNOS responses. Whenever a student responded to a question or follow-up probe, every other student in the group was asked to add to the response and to agree or disagree with that had been said.

Protein Synthesis Modeling Activity: RKT

All students that attended the class completed a protein synthesis modeling activity as part of a unit on genetics and protein synthesis. Protein synthesis is a difficult concept for students to understand because it is complex and dynamic, with processes occurring in time and space (Berger, Lu, Belzer, & Voss, 1994). Approximately three weeks before the modeling activity students began to learn about protein synthesis, specifically how DNA bases are transcribed by messenger RNA, translated by transfer RNA, and synthesized into proteins within cells. Groups of four to six students worked together on a modeling activity as the culminating project of the unit. Students were told that they were going to simulate protein synthesis by making Rice Krispie Treats (RKT). The goal of the modeling activity was for students to recognize that the steps that they were taking to create the RKT model the process of what happens in a cell during protein synthesis. This modeling activity culminated a series of experiments in which students explored mechanisms of genetic inheritance, including simple dominance, recessive traits, sex linkage, and autosomal traits. Besides the RKT activity, students had built geometric models to simulate protein synthesis under guidance from their teacher.

The RKT activity required that students decode a DNA recipe of the ingredients for RKTs. If the students made an error during the transcription or translation phases of the activity, they would end up with distasteful ingredients (i.e., mutations) in their RKTs – Tabasco instead of marshmallows, for example. To start the RKT activity, each group was given a strip of DNA and found the codon where the RKT gene began. Students then used a DNA codon sheet to transcribe the genetic code for the RKT into mRNA codons. If the students made an error in the translation process then their RKT would come out differently than expected because of the simulated mutation. This phase modeled the transcription process in the cell when DNA bases are matched with RNA bases to make a messenger RNA (mRNA) strand. After this the students used an mRNA table to record the corresponding transfer RNA (tRNA) RKT anticodons, then obtained the amino acid ingredients, and assembled them together. This process modeled the translation part in protein synthesis outside of the cell's nucleus when a ribosome attaches itself to the mRNA and then the tRNA matches up with the mRNA codon to produce a polypeptide (a protein made out of a chain of amino acids). Finally, the students shaped their RKT in a pan and baked them. This process was equivalent to protein modification.

After the students completed the RKT activity they filled out a table where they explained each step in the RKT procedure, the corresponding cellular process, where the cell does it, and how the RKT procedure was or was not like what happens during protein synthesis. Students also had three analysis questions to answer: (1) What proteins are involved in the transcription and translation of DNA into the final product of a protein? (2) In your lab, you obtained “amino acid” ingredients from your instructor, which you mixed together. In real life this could be equated to making a polypeptide. The process of shaping the treats into a pan could be equated to protein modification. Where in the cell might this modification process take place?

Note that this activity was much more typical of school science than professional science, even though it spanned three class periods (of 40 minutes each) and involved considerable work for students. The activity was not driven by students’ questions, or even any question really. The steps students took were broadly scripted, although their teacher emphasized that a mistake could be made. The goal of the activity was primarily for students to demonstrate to themselves that genes code for proteins and that mistakes in the transcription of DNA would generate mutations that would change the final protein, usually in bad ways.

Measuring Students Beliefs about Science

VNOS. Views of Nature of Science (VNOS) is a 10 item open-ended questionnaire to measure students’ beliefs about the nature of science, developed by Lederman and his colleagues (2002) for undergraduate students. We modified the questionnaire slightly to simplify the language for high school students (Appendix A.). Although VNOS measures several nature of science themes, we focused on two: the *empirical basis* of science (scientific knowledge is based on and/or derived from observations of the natural world), and *tentativeness* (scientific knowledge is subject to change with new observations and with the reinterpretations of existing observations).

Because of the open-ended nature of the questionnaire, any of the themes potentially can appear in any question. As mentioned at the start of this paper, we focused on these two themes because they are of central importance to students' own efforts to learn science through inquiry. They also seem amenable to direct interrogation with respect to students' own work. Other NOS themes may also fit this criterion, but we chose to focus on these two as a first step towards comparing beliefs about school and professional science.

Interview. Once the RKT modeling activity was completed groups of students were taken out of their science class and into a separate room for an approximately 20 minute interview about their project using a protocol designed for this study (Appendix B.). We designed the first part of the interview to ground students' talk in their own work. The second part of the interview we designed to assess students' beliefs about their own work in relation to scientific theories, evidence, and knowledge change. The last question in the interview was used to assess students' beliefs between professional science and school science.

Analysis

VNOS was analyzed by coding each question with the previously described themes. The method used here was provided by the VNOS developers and followed the strategies used in the published studies using this instrument (Khishfe & Abd-El-Khalick, 2002; Lederman et al., 2002). This was done theme by theme; first, responses to all of the ten questions were read and any text relating to the theme being coded was grouped and copied into another document. Once all of the text pertaining to the theme was sorted from the rest of the text a score was given for that student for that theme in the following way (see Appendix C.).

The first theme coded was empirical basis. In order to score informed on this theme the student would have to say that scientific knowledge is based on and/or derived from observations of the real world, which is then interpreted. A naïve view would be coded if the student said that experimental data is the answer because experiments give facts, which do not need any interpretation. A transitional view would be coded if the student said something that included some, but not all aspects of an informed view.

In order to score informed on tentativeness the student would have to say that scientific knowledge can change and change can result from new observations and/or new interpretations of observations. A transitional view would be coded if the student said either of these. A naïve view would be coded if the student did not say anything related to knowledge change or if they did not respond to this aspect across any of the questions. The first author and a second coder unfamiliar with the study independently coded twenty percent of the VNOS data. Inter-rater agreement was 88%.

After coding all of the VNOS data, we saw that all of the students' responses were coded as naïve. To produce a more fine-grained understanding of students' views of professional science, we used a categorizing analytic strategy, as described by Maxwell (Maxwell, 1996). With this strategy we went back through students' VNOS responses and pulled out common responses to each question as they related to the two themes of *empirical basis* and *tentativeness*. After comparing different responses we categorized them into different themes with different codes. The themes and codes will be described in further detail in the results section. Note that themes are not mutually exclusive, because it was often the case that a student would have more than one of the codes in their response. We wanted to capture everything that the student said, in order to properly characterize their response and so our analysis would fully capture the complexity in their responses. We used this same categorizing analytic strategy to analyze the interview data. We sorted through common responses to each question, and then created different themes and codes. These codes were not mutually exclusive. Twenty percent of the VNOS and group interview data were coded independently by the first and second author to establish coding reliability. Inter-rater agreement was 88% for VNOS and 96% for the group interview.

Results

The results are organized in four different sections. First, we report results about what students said they were doing in the RKT activity. Second, we report results about how students view their work in science class in relation to scientists work. Third, we report results about students' beliefs about the purpose of experimentation. Last, we report results about students' beliefs about the status of scientific knowledge

The Purpose of their Activity

The first question we asked students during the interview was what they thought they were trying to do in the activity. Nine students reported that they were doing the activity so they could understand protein synthesis. These same nine students also said that they were doing the activity in order to make a rice krispie treat. Three students reported that they were doing the activity so they could work with materials. Four students said that the purpose of the activity was to create a simulation. Of these four students half of them recognized that the simulation was to help them better understand protein synthesis.

Student Work in Relation to Scientific Work

Figure 1 shows that all but one student claimed that their work in this activity was like the work of professional scientists. Their reasons for this judgment varied. Reasons that students gave were that their work is just like scientists because they “put things together” like scientists do, because they too are trying to figure something out, because they both experiment, and because they both make theories. There is a large other category in Figure 1. Students were coded as other if less than 3 students gave a particular response. For this question the other category included (a)two students who said that their work was like scientists work, but scientists work is harder, (b)two students said that their work was like scientists because they both take steps, and (c)one student who said that their work was not like scientists’ work because the materials were given to the students and scientists do not have materials given to them.

INSERT FIGURE 1. ABOUT HERE

Students’ Beliefs about the Purpose of Experimentation

Professional science. Figure 2 shows the range of student responses for the purpose of experimentation theme in VNOS. Student responses varied when responding to this question, but students generally said that scientists experiment to gain understanding, find answers, test, and figure something out.

INSERT FIGURE 2. ABOUT HERE

Some typical responses that students gave when we asked them if they thought what they were doing was an experiment and why were: "An experiment is a test."; "To experiment to know things that nobody now or ever thought to have an understanding of our surroundings and what their made of and how they got there."; "An experiment is trying something out, messing with it to see how it works, how it functions, basically you wanna know everything in the object, how to place it were it works. (Everything). Yes because you want to try it out, when your trying it out your experimenting with it basically." However, it is not clear what students mean by the terms that they use; there is great ambiguity in their responses. It is unclear if the students think that testing something, understanding something, or figuring something out, is done as a means to find the "right answer," or if they think that these things are done for different reasons.

School science. Seven students said that the RKT activity was an experiment, while five students said that it was not. The students who said that it was an experiment categorized it that way because they said in an experiment they (the students) are trying to get the right answer, and work with materials. The students who said that the RKT activity was not an experiment said this because in experiments you need to generate your own procedures, and in this activity they did not generate their own procedures. In general students said that an activity can be categorized as an experiment if you are trying to get the right answer, working with materials, and generating procedures (Figure 3).

INSERT FIGURE 3. ABOUT HERE

Students' Beliefs about the Status of Scientific Knowledge

Professional science. All but two of the students wrote that scientists' knowledge can change. Students described three different kinds of change: knowledge is added, knowledge is replaced, or knowledge changes over time (Figure 4). Those students who said that scientific knowledge does not change said so because scientists have the right answer.

INSERT FIGURE 4. ABOUT HERE

School science. All of the students said that their knowledge can change, but their reasons for believing so varied. Figure 5 shows that half of the students reported that their knowledge could change if different materials are used. Five students said that their knowledge can change if new knowledge is gained. For example a student said, “It would change it we found something else like or if we learned some more about it and we feeled that our other answer wasn’t good enough.” Three students said that their knowledge changes because of error. These students said things like, “if we took a wrong step in the directions and we could come up with something different then it probably would change.”

INSERT FIGURE 5. ABOUT HERE

Discussion

The themes evident in students’ responses to questions about professional science are markedly different to their responses about their own work. Students reported differences between the purpose of experimentation and the status of knowledge across the two contexts, although they said the purpose of their school activity was similar to scientists’ work. These findings add to emerging evidence regarding the inconsistency of students’ epistemological ideas, and suggest how school science activities may contribute to this inconsistency. In this discussion we highlight the contradictions students expressed about the purpose of experimentation in school and in science, and about the status of scientific knowledge and their knowledge, and possible sources of knowledge change. We mention areas for future research, including ways to move beyond some of the limitations of this study.

Purpose of Experimentation

The students in this study were well aware of why they were doing this modeling activity, contrary to earlier findings (Brickhouse, 1990). When we asked students to explain the purpose of their school experiments their responses were fairly consistent with what they said about the purpose of professional scientists' experiments. Their responses mirrored the same types of responses reported in other studies (Carey et al., 1989; Sandoval & Morrison, 2003). Students said that they do experiments to find the right answer, or to work with materials, and they said that scientists do experiments to find the right answer, or gain understanding. Exactly what students meant by "gain understanding" is unclear, as they rarely expanded on this idea in either the VNOS questionnaire or interview. They could think that scientists want to gain understanding in order to eventually get the "right" answer, or they could think something else.

When we asked students to compare the work that they did to the work of scientists their responses were very different than what they said about each separately. When students' described the purpose of school experimentation they said things like to get the right answer, work with materials, and invent procedures. However, when students directly compared school experimentation to scientists' experimentation they said that they both figure something out, put things together, experiment, and make theories. Students did not mention anything about finding right answers. While they were extremely vague in their descriptions of likeness, 11 of 12 asserted that their work was just like scientists work.

It is possible that these findings are an artifact of both the VNOS questionnaire and our interview protocol. In answering VNOS, students typically gave extremely brief, reticent answers, inevitably leading to ambiguity. When interviewed four months later, it is possible that students were trying to tell us what they thought we wanted to hear – that they were trying to figure things out just like scientists. Whether this is the case or not, we cannot say for sure. Regardless, students' inability to articulate in any detail what sorts of "things" are figured out, or how experiments help one to do that, underscores both their unfamiliarity with the nature of scientific work and the general failure of science instruction to help them understand the purposes of their school science activity.

Status of Scientific Knowledge

All of the students agreed that both their scientific knowledge and professional scientists' knowledge can change. Yet, the reasons that students gave for the sources of change in their own work were very different from the reasons they gave about the sources of change in professional scientists' work. When students talked about their own work and how it may change they focused on the immediate effects of changing some aspect of the experiment, such as the DNA sequence, or the ingredients used. Granted these sorts of alterations to the experiment would change the immediate outcome of the experiment because students would have different flavored RKTs. Yet, these specific changes of details would not change the big picture of the experiment; how protein synthesis is conducted.

When students talked about scientists' work and how it may change they focused their responses on larger level changes that were not as detailed or specific. They said that either adding new knowledge, or replacing knowledge will cause scientific knowledge to change. Students may have reported vague, and broad responses about sources of change because they had nothing concrete to draw from to be able to explain how professional scientists' knowledge changes. They could be more specific with their own work because they are able to speak from their own experience. At the same time, when talking about their own work, students did not describe how changes in materials or outcomes would affect their knowledge, but only mentioned that it would. Overall, students' responses about change are consistent with previous studies where students generally say that "right" ideas replace "wrong" ones (Driver et al., 1996; Khishfe & Abd-El-Khalick, 2002; Lederman & O'Malley, 1990; Linn & Songer, 1993).

Implications, Limitations, and Open Questions

We have argued elsewhere that neither studies of students expressed ideas about professional science or studies of students' science practices in school are sufficient to describe the epistemological ideas that guide students' science learning. Rather, such work must be combined with efforts to probe students' ideas about their own work and its relation to professional science (Sandoval, 2003). This study was a first attempt in that direction. It might be that its main value is in underscoring the difficulty of this agenda. Students are just not articulate in expressing their ideas about science. The VNOS questionnaire was developed after careful analyses of the weaknesses of other instruments developed over the last fifty years (Lederman et al., 2002), yet students here found it difficult to complete and were decidedly terse in their responses. Our own interview protocol was designed to ground epistemological issues in terms of students' own work, but again the brevity of their responses suggests that they are unsure of how to talk about such issues.

Over the course of several decades, the predominant method for studying students' epistemological beliefs about science has been to ask them about the nature of professional science. This approach has been critiqued on both theoretical and methodological grounds (Kelly, Chen, & Crawford, 1998; Lederman, Wade, & Bell, 1998), as well as being suggested as irrelevant as an influence on students' learning strategies (Hogan, 1999). These critiques have all suggested that observations of students' practices enable better inferences about students' epistemological ideas than interrogations of their expressed beliefs. We are sympathetic to this point of view, although observations of practice seem best able to illuminate forms of students' sense-making in science, but not necessarily the epistemological ideas that students bring to bear on such sense-making (see Sandoval, 2003). We maintain that understanding these epistemological ideas remains an important research goal.

Others have attempted to ground studies of epistemological beliefs in contexts more familiar to students, but not necessarily in students' own work. Linn and Songer developed a survey to assess epistemological beliefs that included questions that asked students to judge the adequacy of experiments or how competing scientists might resolve a disputed claim, as well as questions about students' strategies for learning science (Linn & Songer, 1993; Songer & Linn, 1991). As with earlier studies, however, they attempted to classify students' into broad epistemological types (seeing science as 'static' or 'dynamic'), but found that more than 60 percent of students could not be classified neatly into one of these types. Driver and colleagues grounded their interview and survey protocol in specific contexts, such as reasoning about electricity to assign students to broad epistemological levels (Driver et al., 1996), although later analyses showed that students responses across various contexts were not consistent (Leach et al., 2000), undermining assignment to clean epistemological levels (cf., Sandoval & Morrison, 2003).

Although we know of a few other studies that have examined students ideas about science learning in relation to their epistemological ideas about professional science (Brickhouse, Dagher, Letts, & Shipman, 2000; Hammer, 1994; Linn & Songer, 1993; Roth & Roychoudhury, 1994; Songer & Linn, 1991), we believe this study is unique in asking students directly to reflect on explicitly epistemological issues of their own work. Our assumption prior to the study was that students' beliefs about their own work were likely to be different than their ideas about professional science. Our findings suggest that students see the purpose of experimentation in school and professional science similarly, as a vague sort of test. It remains unclear from our findings whether or not students believe school experiments are the same kind of "test" or test the same sorts of things that professional science experiments test. The clearest difference between their own and professional work seen in students' responses includes the reasons they gave for knowledge change in the two contexts. Students apparently believe that their school-generated knowledge will change when or if they discover a mistake, whereas professional science knowledge can be added to or revised in unspecified ways.

We see three features of this study that limit the generality or robustness of our findings. First, our sample was quite small and we may have discovered different themes or patterns of themes in a larger sample. Second, and more problematic, is that the modeling task that students were interviewed about is probably too much like a school task to adequately tap into students' epistemological ideas about their own knowledge construction. For those interested in how inquiry-oriented reforms might help students to develop sophisticated scientific epistemologies, and what the obstacles to that are, it would be more useful to ask students to explain their epistemological perspectives on more authentic inquiry tasks. We are pursuing such work in current and future studies.

Finally, we are concerned at the lack of depth in students' responses to either the VNOS questionnaire or our interview, and wonder how students' ideas can be adequately probed in this area. The issue is especially critical in light of the fact that the practical epistemological ideas that students may hold, the epistemological beliefs that underlie their own practice (Sandoval, 2003), remain poorly understood as NOS research has focused on conceptions of a distant professional science removed from students' experience. Our aim is to pursue an interviewing strategy that remains closely tied to students' work and the artifacts that they might generate from their own inquiry, although our findings here emphasize that the form of such artifacts and the kind of work involved in creating them must be carefully considered.

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Figure Captions

Figure 1. Students’ responses to how their school science work is similar to scientists work.

Figure 2. Students’ responses to the purpose of scientists’ experiments

Figure 3. Students’ responses to the purpose of school experiments

Figure 4. Common Student responses to the sources of change in professional science

Figure 5. Students’ responses to the sources of change in school science

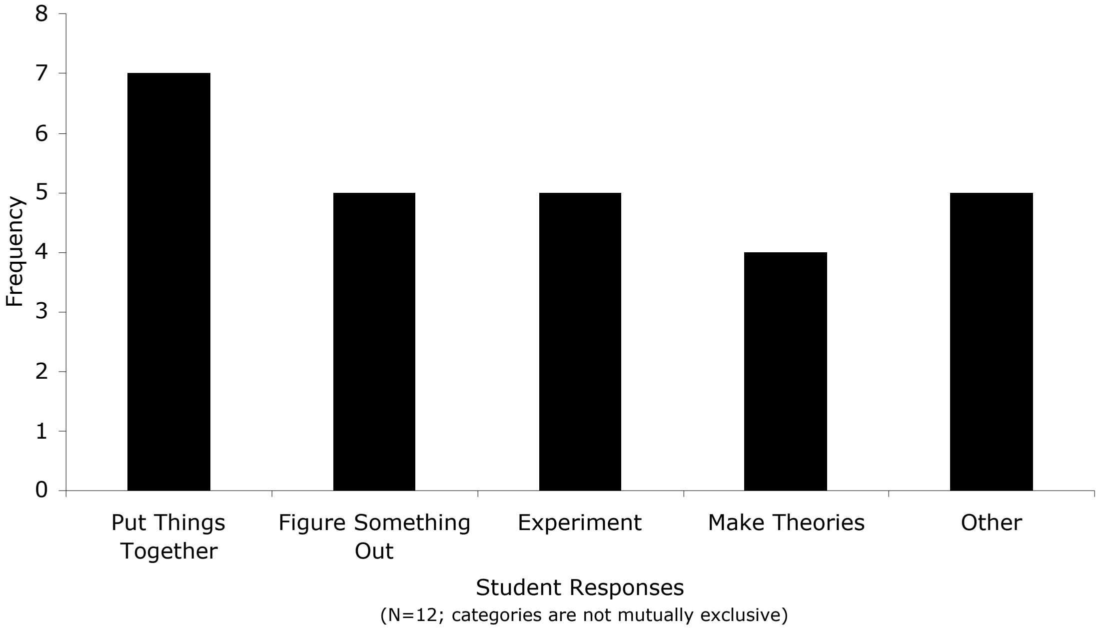

Figure 1.

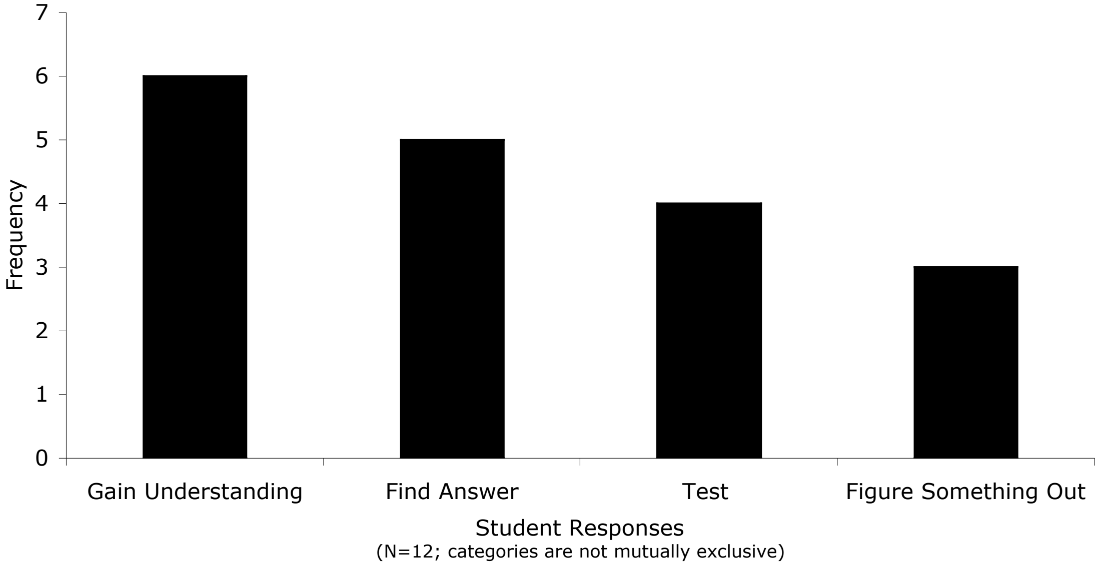

Figure 2.

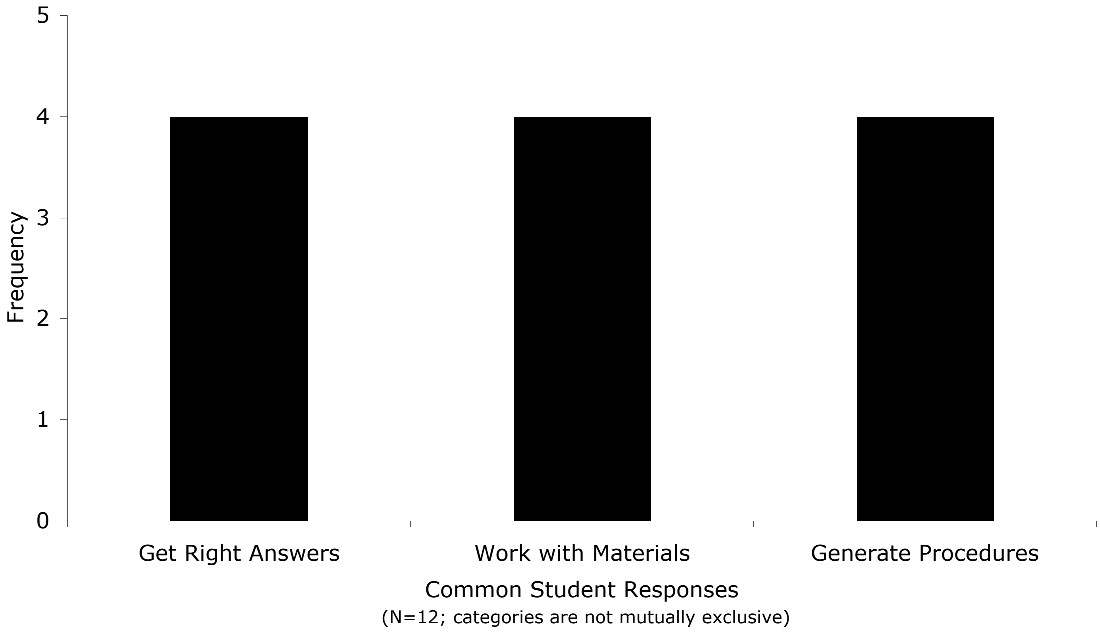

Figure 3.

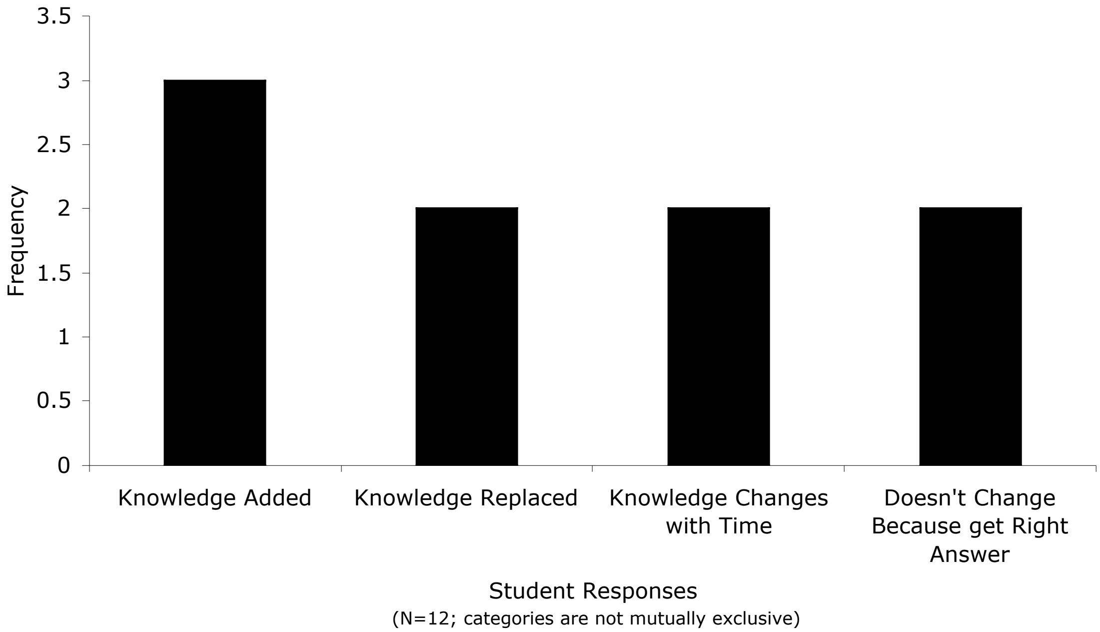

Figure 4.

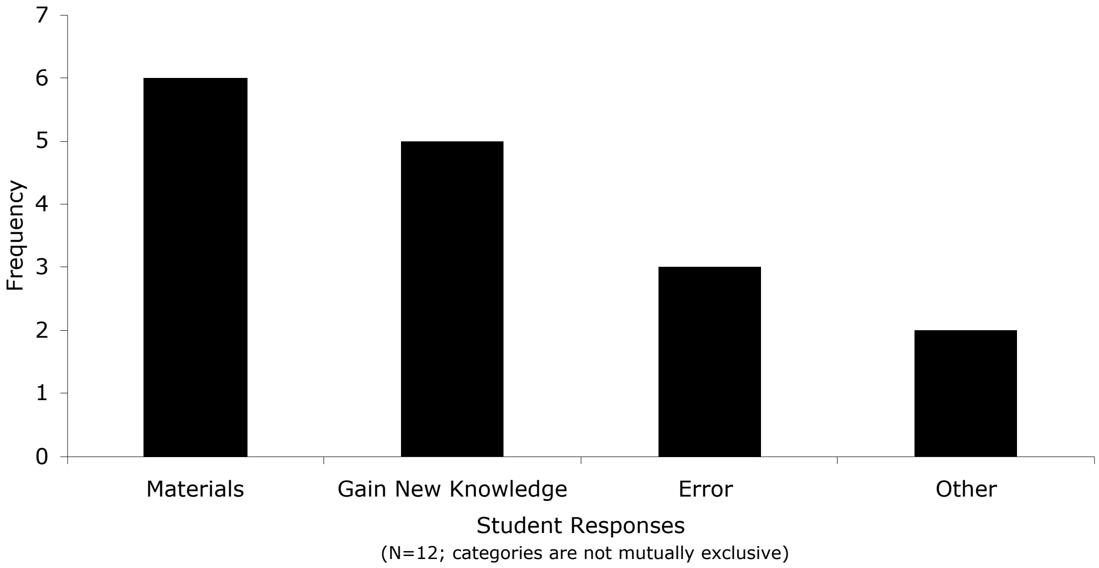
7
6
5
4
3
2
1
0
Frequency
Materials
Gain New Knowledge
Error
Other
Student Responses
(N=12; categories are not mutually exclusive)

Figure 5.

Appendix A. : VNOS

Altered text, from the original VNOS, is in italics. Students saw each question on a separate page with the following instructions*:*

Instructions

- Please answer each of the following questions. You can use the back of a page if you need more space.
- *Please answer each question **fully**. The more you write, the better we can understand what you mean.*
- **There are no "right" or "wrong" answers to the following questions. We are only interested in your views on a number of issues about science.**

1. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different *from other ways of knowing about the world* (e.g., religion, philosophy)?

2. What is an experiment?

3. Does the development of scientific knowledge **require** experiments?
   - If yes, *use an example to explain why.*
   - If no, *use an example to explain why.*

4. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change?
   - If you believe that scientific theories do not change, explain why. Defend your answer with examples.
   - If you believe that scientific theories do change: (a) Explain why theories change? (b) Explain why we bother to learn scientific theories? Defend your answer with examples.

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

6. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence **do you think** scientists used to determine what an atom looks like?

7. Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain are scientists about their characterization of what a species is? What specific evidence **do you think** scientists used to determine what a species is?

8. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these **different conclusions** possible if scientists in both groups have access to and use the **same set of data** to derive their conclusions?

9. Some claim that science is infused with social and cultural values. That is, science reflects the social, political *and* philosophical *values*, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is ***not*** affected by social, political, and philosophical values, and intellectual norms of *society*.

   - If you believe that science reflects social and cultural values, explain why. Defend your answer with examples.

   - If you believe that science is universal, explain why. Defend your answer with examples.

10. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?

   - If yes, then at which stages of the investigations you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate.

   - If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

Appendix B: Group Interview Protocol

Today I want to talk to you guys about the genetics project that you just finished up. I am going to ask you a bunch of questions, but there are no right or wrong answers to any of the questions. I am just interested to see what you think about different things. Okay? Any questions before we start?

(1) Can you explain to me what you think you were trying to do in this activity? ((if they just say something like simulate protein synthesis then ask them to tell me some more about what that is because I wasn't here when you guys learned all of that stuff and did this activity))

  (A)*PROBE*: Does anyone have anything to add to that?
  (B)*PROBE*: Does anyone else have a different idea?
  (C)*PROBE*: Does everyone agree with one of these ideas?

(2) Why do you think you were doing this activity? ((if same answer as #1 then ask what was the point of it?))

  (A)*PROBE*: Does anyone have anything to add to that?
  (B)*PROBE*: Does anyone else have a different idea?
  (C)*PROBE*: Does everyone agree with one of these ideas

(3) Do you all think that what you were doing here was an experiment or not, and also tell me why you think so?

  (A)*PROBE*: Does anyone have anything to add to that?
  (B)*PROBE*: Does anyone else have a different idea?
  (C)*PROBE*: Does everyone agree with one of these ideas?

(4) In this activity were you trying to get evidence for or against some theory, or hypothesis, or law, or something?

  YES PROBE: What was the theory/hypothesis/law and how did this help you to get evidence for or against it?

    (A)*PROBE*: Does anyone have anything to add to that?
    (B)*PROBE*: Does anyone else have a different idea?
    (C)*PROBE*: Does everyone agree with one of these ideas?

  NO PROBE: What were you trying to do?

    (A)*PROBE*: Does anyone have anything to add to that?
    (B)*PROBE*: Does anyone else have a different idea?
    (C)*PROBE*: Does everyone agree with one of these ideas?

(5) How do you think your ideas here [resp to q's] might change if you did this activity again? ((want to know where they think the sources of change or error are coming from, provide necessary probes))

(A)*PROBE*: Does anyone have anything to add to that?
(B)*PROBE*: Does anyone else have a different idea?
(C)*PROBE*: Does everyone agree with one of these ideas?

(6) Do you think other students in your class, or Mrs. Bird's other classes came up with different ideas then what you guys did when they did this activity? Why?

(A)*PROBE*: Does anyone have anything to add to that?
(B)*PROBE*: Does anyone else have a different idea?
(C)*PROBE*: Does everyone agree with one of these ideas?

(7) How do you think what you did here is like or not like what scientists do?

(A)*PROBE*: Does anyone have anything to add to that?
(B)*PROBE*: Does anyone else have a different idea?
(C)*PROBE*: Does everyone agree with one of these ideas?

CLOSING: Okay well that was the last question that I wanted to ask you guys, do you guys have anything that you want to add to any of the other things we have talked about, or are there any questions that you want to ask me?

Appendix C: NOS aspects and descriptions that serve as a basis for evaluation of VNOS responses

Aspect	Description
Tentativeness	Scientific knowledge is subject to change with new observations and with the reinterpretations of existing observations. All other aspects of NOS provide rationale for the tentativeness of scientific knowledge
Empirical basis	Scientific knowledge is based on and/or derived from observations of the natural world.
Subjectivity	Science is influenced and driven by the presently accepted scientific theories and laws. The development of questions, investigations, and interpretations of data are filtered through the lens of current theory. This is an unavoidable subjectivity that allows science to progress and remain consistent, yet also contributes to change in science when previous evidence is examined from the perspective of new knowledge. Personal subjectivity is also unavoidable. Personal values, agendas, and prior experiences dictate what and how scientists conduct their work.
Creativity	Scientific knowledge is created from human imaginations and logical reasoning. This creation is based on observations and inferences of the natural world.
Social/cultural embeddedness	Science is a human endeavor and, as such, is influenced by the society and culture in which it is practiced. The values and expectations of the culture determine what and how science is conducted, interpreted, and accepted.
Observations and inferences	Science is based on both observations and inferences. Observations are gathered through human senses or extensions of those senses. Inferences are interpretations of those observations. Perspectives of current science and the scientists guide both observations and inferences. Multiple perspectives contribute to valid multiple interpretations of observations.
Theories and laws	Theories and laws are different kinds of scientific knowledge. Laws describe relationships, observed or perceived, of phenomena in nature. Theories are inferred explanations for natural phenomena and mechanisms for relationships among natural phenomena. Hypotheses in science may lead to either theories or laws with the accumulation of substantial supporting evidence and acceptance in the scientific community. Theories and laws do not progress into one another, in the hierarchical sense, for they are distinctly and functionally different types of knowledge.

Judgments of respondents' views are made independently for each aspect.

Naïve	**None** of the underlined ideas are mentioned in the response.
Transitional	**Some** of the underlined ideas are mentioned in the response.
Informed	**All** of the underlined ideas are mentioned in the response.

Coding strategy:
-Examine each question for language related to each aspect.
-Collect all language related to an aspect together (e.g., any language judged as being about tentativeness should be collected, etc.).
-Judge each collective response for each aspect independently. There is no need to make an overall judgment.