Conceptualizing the nature of science: Extra-rational evaluations of tiny atoms, round planets, and big bangs

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ABSTRACT: This research considers the nature of how learners conceptualize nature of science ideas. Specifically, we look at how the concept of "science as a way of knowing" exists in and interacts with a framework of other nature of science conceptions. We conducted a qualitative study with four learners to understand what their conceptions of the nature of science are, how these conceptions are cognitively justified, and how these conceptions interact with other aspects of their conceptual framework and conceptual ecologies. We found that, even when learners could explicitly describe aspects of the nature of science, the conceptions that they reflected could change greatly as a result of differing situations and research probes, especially when extra-rational factors (emotions, values, etc.) were evoked in the learner. Our findings suggest that conceptual change theory needs to further address the interaction of extra-rational factors on learning, and that research regarding nature of science conceptions must take into account that such conceptions are not determined solely by rational processes.

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Even at this late date, I am still full of rage at a natural order which would have permitted the evolution of something as distracting and irrelevant and disruptive as those great big brains . . .

Kurt Vonnegut (1985), *Galapagos*

We will begin this discussion with an assertion: Preservice elementary teachers are not philosophers. This is not too surprising, given the fact that they are training to be teachers rather than philosophers. Yet, as science methods instructors, we find ourselves pushing these teachers-to-be to become as conversant with the philosophy of science as philosophers, and to provide their students with a similar philosophical familiarity, albeit on an elementary level. While this goal may seem overly lofty, we argue that the current emphasis on the *nature of science* (NOS) in the science education reforms requires such philosophical familiarity.

But clearly, understanding the NOS is difficult (e.g., Lederman, 1992). One reason for this lies in the fact that the concepts of NOS are so complex, being largely philosophical and based on abstract ideas rather than physical actions or objects; and, these particular concepts trace back to the very root of what knowledge and knowing is (Johnston & Southerland, 2000). What science is represented to be on television versus what it is represented to be by a philosopher or a theoretical particle physicist can be very different things. It is no wonder our preservice teachers often leave our classrooms more confused on NOS issues than when they entered.

What's more, as has been described in the literature (Abd-El-Khalick & Lederman, 1998), we seldom explicitly address NOS concepts in classroom settings. Perhaps because they are difficult concepts to negotiate and learn, we have a tendency *not* to teach them in our classrooms. Thus, there exists a vicious feedback loop: We do not explicitly teach that which we do not ourselves understand, and as a result, our students never come to appreciate that NOS concepts even exist. When the concepts themselves are not explicitly addressed, they can be assumed to be trivial rather than fundamental. Learners, if they ever become teachers themselves, take this assumption with them into their own classrooms.

The problem is even more complicated and troublesome than this. If we do make explicit attempts to teach NOS understandings, consider that we are asking our learners to think about knowledge, reality, and the processes of understanding when we ask them to think about the NOS. Such considerations could naturally have deep interaction with a learner's personal beliefs, motivations, and attitudes – that which goes beyond the concepts that lie within the reach of logical, rational thinking and are more deeply influenced by what we call extra-rational factors. This research describes a very deep and complicated interaction between four learners' understandings and teachings of what science is and how such knowledge interacts with extra-rational evaluations.

Background

In science education, research into conceptual change and alternative conceptions, and research analyzing nature of science (NOS) conceptions both have been prominent in the field. Our work has attempted to unite these two fields, in the hope that both will be better informed by such an intersection. Specifically, we focus on the conception within the nature of science called *way of knowing* (Lederman, 1998) – the idea that science is one very specific means of understanding the world, and that the understanding it produces is directly affected by its means (Poole, 1996; Southerland, 2000). We look at how such an abstract concept not only is determined by logical, deductive thought processes, but by a learner's personal values and affective associations with a particular concept.

Conceptual change theory has enjoyed a varied and widespread use in science education. Stemming largely from the works of philosophers of science such as Kuhn (1970), science educators considered how individual concepts, like scientific ones, have an inertial tendency to stay fixed. With conceptions that are particularly deeply rooted in one's cognitive structure, it is thought that a kind of conceptual revolution must take place in order for a new idea to replace the old one. This, it was suggested, can only take place once the learner understands the weakness of his existing conception, finds the new idea plausible, understands the new idea, and realizes that the new idea could be even more useful and applicable than the previous one (Posner, Strike, Hewson, & Gertzog, 1982). It is suggested that many of our most sticky of conceptions remain intact due to the fact that the pre-requisites for such a replacement are seldom fully realized.

While Strike and Posner have continued to clarify and refine their original theory (Strike & Posner, 1985, 1992), others have also contributed further clarifications and variations on the conceptual change theme. Many of these address more explicitly the way that concepts are interconnected and structured, such as is described by Vosniadou (1994), diSessa (1993), or Chi (1993). Other researchers address more explicitly the extra-rational factors that influence (or inhibit) conceptual change (Demastes-Southerland, Good, & Peebles, 1995; Dole & Sinatra, 1998; Pintrich, Marx, & Boyle, 1993). If nothing else, these pieces of research re-emphasize the fact that conceptual change (and learning in general) is a complicated process that is effected and affected by many factors, both those internal and external to the learner, and both those rational and extra-rational.

It is well documented that NOS conceptions have been difficult for students and teachers to fully understand (e.g., Abd-El-Khalick, Bell, & Lederman, 1998; Abell & Smith, 1994; Gess-Newsome, Southerland, & Johnston, 2000; Lederman, 1992, 1998; Southerland & Gess-Newsome, 1999) . What *can* be demonstrated is that instruction that most explicitly addresses NOS concepts (Abd-El-Khalick & Lederman, 1998), encourages learners to be aware of and reflect upon their own conceptions (Akerson, Abd-El-Khalick, & Lederman, 2000), and/or causes dissatisfaction with their previous conceptions (Akerson & Abd-El-Khalick, 2000) is most effective (though not completely effective) at enabling the learning of NOS understandings most compatible with the standards of science education reform (AAAS, 1990, 1993; National Research Council, 1995; National Science Teachers Association, 2000).

What is less well documented is *why* NOS concepts are so evasive for learners in the first place. Further, conceptual change theory, while much more articulated than it was two decades ago, still has far to go to fully describe the cognitive processes and structures utilized in replacing one concept with another. Thus, a potentially fruitful research pursuit would be to integrate two lines of research into one: Analyze NOS conceptions from the perspectives of conceptual change theory in order to better inform both areas of research.

NOS conceptions are especially informative for conceptual change research because they have the potential to be so interactive with a learner's conceptual ecology – the overlying conceptual architecture that affects one's conceptions, including one's affective and emotional attachment to a concept and values pertaining to a concept (Demastes-Southerland et al., 1995; Pintrich et al., 1993; Strike & Posner, 1992). How one perceives the nature of science to be, as is demonstrated in this study, is not only pieced together through her formal classroom and other education experience, but through her life experience and her personal values and commitments. We contend that the recognition of such an interconnection is not only informative to the literature on NOS conceptions, but to the literature regarding conceptual change.

Setting the stage

We viewed this research as being naturalistic, in that the researcher who collected data (first author) tried to act as an outsider, creating a qualitative description of the research participants' conceptions of science. At the same time, it was of the constructivist genre of research (Novak, Mintzes, & Wandersee, 2000) because the researcher's participation, in conjunction with that of the student participants, made the collection of data what it is (as presented in the following sections). However, we still view ourselves as a postpositivists, claiming that there exists some realist truth towards which research can help us converge, and that this construction has helped to piece together elements of said truth (Guba, 1990). Yet, one must keep in mind that multiple influences, including those of the researchers, have helped to shape the data and its interpretation. In a qualitative study such as this, these multiple influences are unavoidable, yet they also help to produce the depth of information desired in this research.

The scene

The participants of this study were students of a science course co-offered by the physics and chemistry departments of Bonneville State, a regional state university in the intermountain west with a population of about 14,000 students. The course, *The Principles of Physical Science*, fulfilled a general science requirement of the university, and was one route to fulfilling a science laboratory requirement for the elementary education program at Bonneville State. Instructing this course were two college of science faculty (one from chemistry [Dr. Steinbeck] and one from physics [Dr. Hemingway]) who had each traditionally taken a particular interest in education and teacher preparation. As a result, this course catered to students who were intending to enroll in the elementary education certification program of the university.

In addition to being dedicated and gifted educators, these instructors had visions of science literacy that mirrored reform documents of science education (AAAS, 1990, 1993; National Research Council, 1995). As documented in a brief questionnaire and in informal conversations, Steinbeck emphasized that elementary teachers should have an idea of "how science is studied" in addition to understanding more traditional concepts that are fundamental to physical science (SS_Q1). He contrasted this to typical elementary school curricula, which he portrayed as overemphasizing the memorization of facts. Hemingway, who was responsible for teaching the first half of the course and the explicit instruction of NOS concepts, described science as "an active process of investigating" in order to uncover explanations of "how the observable world works" (BC_Q1). As a result of actually doing science in this course, students he has seen have become more comfortable not only with the science concepts but also with the portrayal and practice of science in an elementary classroom.

The researcher's presence in the course consisted of attending all class lectures and laboratories. In class lectures, the researcher sat with students in the class, taking field notes and tape recording lecture and any discussion. Occasionally, the researcher would ask a question as any student in the class would have the opportunity to, and in some specific instances he was asked to participate along with students in a class activity. (For example, the researcher's shoes were contributed for an activity and discussion on categorization.) In laboratory sessions, the researcher wandered among the students and helped with any problems or questions that they may have had. While not having the same authority in the class as one of the two instructors (e.g., had no influence on grades), the researcher was regarded by students as a source of help and information. So, while he was observing and taking field notes of lab sessions, he was also interactive with students in the laboratories. In addition to all tape recordings and field notes, all class sessions were described in a field journal (Richardson, 2000). This journal was comprised of narrative accounts of what took place in class sessions.

The course was structured around lectures (twice a week, 50 minutes each) and a lab (once a week, three hours each). During lecture, concepts were explained, utilizing classroom demonstrations and student participation. Concepts included not only those from physics and chemistry, but also those regarding the nature of science, how it is conducted, and the assumptions upon which it is based. Lab sessions were used to first explain (via lecture and demonstration) concepts specifically applicable to the exercise of the week, and then for students to conduct experiments regarding these concepts, which could readily be adapted for use in the elementary school setting. Explicit attention of the curriculum not only was focused on traditional physical science concepts, but also the course explicitly focused on the nature of science and scientific practice, especially as it applied to the elementary school classroom. Of 23 lecture topics outlined in the course syllabus, the first five encountered had to do with the nature of science and its sub-concepts. As listed on the course syllabus, these included:

- The nature of science: how it is studied, the scientific method, observations based on the senses.
- Measurement: measurement systems, measurement standards.

- Classification.
- Experimentation: experimental design, characteristics of good experimenters.
- Representing data: relative magnitudes, graphing.

In addition, the process of science and how it can be used in everyday reasoning, as well as in the classroom, was emphasized throughout the course. This is particularly true in the laboratory sections of the course, to which a large percentage of time (up to three out of five student contact hours each week) and grading (twenty percent of the final grade) was devoted. The researcher sat in on class discussions and labs in order to verify that there did exist an emphasis on the nature of science.

This class had a novel approach, exhibiting a balance between emphasizing science, the nature of science, and methods for elementary school teachers. This blend of emphases had the potential to provide the rich science background that a preservice elementary teacher should receive. Especially noteworthy, however, was that NOS concepts were taught explicitly through direct instruction and laboratories, which has been found to be much more effective than other traditional (i.e., implicit or historical addressing of NOS concepts) curricula (e.g., Abd-El-Khalick et al., 1998; Gess-Newsome, 1999; Lederman, 1998; Lederman, Schwartz, Abd-El-Khalick, & Bell, 1999). Even though this course did not emphasize NOS concepts as much as these other studied courses have, nor did it utilize reflective activities to emphasize NOS conceptions as recently shown to be effective by Akerson and colleagues (Akerson et al., 2000), in our estimation, the emphasis that did exist on NOS concepts was explicit and deliberate. Moreover, these concepts were covered early in the course, before most of the interview probes were used. It was for these reasons that, despite the recognition that conceptual changes in NOS are difficult, we expected at least moderate gains in student NOS understandings.

Explicit instruction on NOS concepts was documented in field notes and field journals. It should be taken into account that the greatest amount of class time spent on NOS concepts was at the beginning of the course, during the first three weeks. After these first three weeks, most NOS coverage that was made explicit was tied in with other concepts (doing an experiment in Newton's laws, for example) and was not the primary focus of the lesson. However, a theme that was emphasized throughout the entire course was the modeling of how science proceeds: how it collects data, evaluates evidence, and builds explanations. This was incorporated into lecture demonstrations as well as into the laboratories in which the students participated. Also, Hemingway, who was responsible for lectures concerning NOS concepts, was especially apt to make specific comments about the abilities and limitations of science (e.g., "I shouldn't say 'truth' in a science class, but that's the best we know," [Lec7.2]) and how science works (e.g., describing how the nature of light was not so much discovered through direct observation as it was implied through Maxwell's theoretical analysis [Lec10.1]).

The cast

The most important part of the cast for the purposes of this study were, of course, the students. Of the twenty-five students who completed the course, all but one were majoring in elementary education. These elementary education majors were at a preliminary stage in their course of study, having not been officially accepted in the teacher certification program, but taking coursework required for this program. The great majority of students were female – there were only three males enrolled in the course. As Bonneville State is a regional undergraduate university, students of this class typically came from the local area and were living off campus, either with family or a spouse. Most students had a limited science background (i.e., non-science majors), but were willing to see how science could be applied to their eventual classroom practice and pedagogy. Many students enrolled in this course because, in addition to satisfying general education and major coursework, it was preferable to other courses in physics, chemistry, the life sciences, etc. Many took the course with little preference for one mode of scientific discipline over another, and had ended up in this particular class because an advisor suggested it and/or because it fit easily into their class and/or work schedule.

Case study selection

The case studies were meant to study conceptions undergoing development and change. They were also meant to study such conceptions for preservice elementary school teachers. Thus, it was important to be careful to select candidates purposefully, through criterion-based procedures (LeCompte & Preissle, 1993). The criteria for the case study participants of this research were that the students intended to be elementary teachers and that they exhibited a potential for conceptual change in the area of NOS conceptions. Furthermore, the participants were sought out in order to have a range of NOS understandings. Finally, some attempt was made to identify students who were most willing and able to participate in interview sessions that were held roughly every two weeks during an entire semester.

Of this class' population of students, four case study participants were selected for this research. To select students, a survey asking for demographic information was utilized. This was used to select students who were preservice elementary teachers. In addition, two NOS instruments were used: a science questionnaire (as first employed by Abell and Smith (1994)), and the Nature of Scientific Knowledge Survey, or NSKS (Rubba & Anderson, 1978). By analyzing the responses to this questionnaire and survey, a group of four students was selected so that they both exhibited the potential to gain in their NOS understandings from this course; and that they each showed some differences in their original conceptions. As it turned out, such features were relatively easy to find, and all four case study participants described in the data to follow were willing and cooperative in this study.

While four candidates were chosen based on these criteria, one participant had to drop out of the study early in the semester. In her place, Joni was asked to and showed a great willingness to volunteer in the research. Not only were Joni's questionnaire and NSKS results of interest, but her outgoingness in the course demonstrated that she would be able to contribute quite effectively to the case study data. Michelle, Laura, and Jamie were the other case study volunteers. Each of these individuals is identified by a pseudonym that was either selected by herself or by the researcher.

Data sources

In order to describe in detail the case study participants' NOS conceptions, in-depth, qualitative case studies were in order. Besides the preliminary instruments described above, each case study learner participated in seven interview sessions, each containing multiple probes. In addition, each participant completed a final, written instrument that mirrored the preliminary science questionnaire and NSKS. All interview probes were tape recorded and transcribed by the researcher. Transcripts included not only all verbal communications, but also noted instances of laughter, pause, sighs, exclamation, etc.

The majority of the data for these case studies were produced using multiple qualitative probes of the four participants. These probes were primarily based on a variety of interview techniques. These included not only direct questions about the nature of science (e.g., "What is science? What is the purpose of science?"), but also "interviews about instances" (Southerland, Smith, & Cummins, 2000), or "IAIs". These probes had students respond to various prompts, such as a video, a reading passage, or a specific situation. One such situation is known as a "critical incident," in which the learner is asked about a potential classroom situation in which she is the hypothetical teacher (Hewson & Hewson, 1989; Nott & Wellington, 1998). For this research, our data analysis was especially focused on a set of CI's for which case study participants explain how they would handle some student protests in the classroom. Another IAI which proved enlightening was with regards to the participants' own experiences in the physical science class they were enrolled in.

Data analysis

The data analysis of this study utilized the constant comparative method of analysis, also known as grounded theory (Strauss & Corbin, 1998). This was modeled after and similar to the analysis used in other work (e.g., Southerland & Gess-Newsome, 1999). The idea of this data analysis was that theory could be produced by the data and their analysis. However, such a production could not follow from a single reading of the data. The data were analyzed in three distinct stages, similar to those described by Strauss and Corbin (1998). For this research, the three stages could be viewed as three filters and tests of the data analysis. That is, each stage used the data to test and negate or validate any meaning that was being made. For example, the first stage of data analysis suggested that Jamie's view of the purpose of science was not clearly defined; however, a subsequent stage of data analysis tested this interpretation of the data by referring to the data (interview transcripts) itself, and showed that the previous assessment was in fact inaccurate.

The first stage of data analysis took place immediately following interview sessions. As data were collected through interviews, field notes were compiled in addition to the audiotape recording of each session. Immediately following each interview session, a narrative field journal entry was written, based on field notes and the researcher's own reflection on the interview session, its probes, and case study responses (Richardson, 2000). As each interview session was reconsidered, specific themes from the session were identified and described in a typed response (Miles & Huberman, 1994; Ryan & Bernard, 2000). Essentially, these entries in the field journal became their own set of data, and reflected the researcher's interpretations of the interview probes and responses immediately after they took place.

After multiple interviews and probes were completed, journal entries were used to further validate (or negate) particular interpretations (Strauss & Corbin, 1998). This began a second stage of data analysis. This second stage of analysis compiled data (in the form of field journal entries and field notes) from individual probes to summarize conceptions as they stood at one particular stage in time during the semester. The semester was segmented into three thirds (each roughly 5 weeks), each representing one of these stages. This compilation of data was documented in a table. One table was created for each stage of each case study participant. The columns of each table represented one conception being studied (the definition of science, science as a way of knowing, and the tentative nature of science), while the rows of each table documented different aspects of each concept as it was conceived by the learner at that represented stage. (For other examples of this kind of coding, see Loving & Foster, 2000; Tyson, Venville, Harrison, & Treagust, 1997; Venville & Treagust, 1998)

The third stage of data analysis looked to test the previous analyses, and revised and expanded the table data. This was done by analyzing the transcripts of the interview data and writing summative narratives of each probe. These narratives include interpretive and descriptive summaries (Richardson, 2000) and supporting excerpts from interview data. The interpretations of the narrative and the interpretation of the tables were compared. In cases where the two interpretations of the data were consistent, information from the narratives and interview transcripts was used to further clarify and expand information included on the table. In cases where the narrative contradicted the original information of the table, interview transcripts were referred to in order to settle such a disagreement. In this manner, all interpretations of the data have been tested and verified (Strauss & Corbin, 1998).

While the data which were collected and analyzed were part of a larger project (Johnston, 2001), it became clear that specific pieces of data were especially comparable between the learners studied. Specifically, three probes were focused on: One IAI, a questioning about the structure of the atom as it was presented in class, and two CI's, questions about student protests to the Earth being a sphere and about Big Bang theory. While our descriptions of the learners are based on a wide variety of data, our primary thesis is concerned with these three specific probes and how they interact with each learner's conceptual ecology, as described in the following section.

Results

In this section we first present a brief account of what a classroom session looked like for the case study participants being studied. Following this is the data which documents our case study participants' conceptual ecologies, and finally their conceptions of the NOS.

The class

The class discussion of the first class session of the third week provided a specific example of the explicit degree of NOS concept coverage in this course. Hemingway introduced this class discussion with a yo-yo that rested on a table so that it could roll like a wheel. He suggested that the class predict how the yo-yo would travel if he pulled on its string a particular way, noting that such a prediction was part of the scientific process. This was repeated for the situation in which the yo-yo's string was pulled in the opposite direction. The yo-yo's motion was in a manner which was unexpected by the members of the class, and this led to a discussion on how science begins with observations and questions, and how science focuses on trying to solve these kinds of questions. Continuing to use the yo-yo as a poster child for scientific experimentation, Dr. Hemingway and the members of the class came to the consensus that "tests" (as stated by a member of the class, Lec3.1, p. 2) or "experiments" (as stated by Hemingway, p. 2) were the means towards understanding what kind of behavior the yo-yo exhibited under different experiments. This treatment was used to describe what scientific method looks like, although Dr. Hemingway was careful to note that any scientific method should "not seem mechanical" (p. 3). After some more discussion of scientific method, the class session focused on other elements of the scientific process. Specifically treated were the descriptions of a scientific fact, hypothesis, law, and theory. Each was described in some detail, emphasizing that a fact is something which we typically observe and may constitute a piece of data; a hypothesis is "a proposed explanation" of some phenomenon (p. 5); a law is "a well tested generalization of how nature behaves" (p. 5); and a theory is what science strives towards, generalizing many aspects of nature with a grand explanation. Dr. Hemingway noted that laws and theories are difficult to distinguish sometimes, and that for the purposes of the course they could be viewed as approximately the same. However, he also made explicit mention of the typical misconception that theories are speculative, and he re-emphasized that there was in fact little scientific doubting of an explanation which has the status of a theory. Finally, Dr. Hemingway made the point that scientific knowledge must be testable, and gave some examples of statements which can not be tested. As the class session was nearing its completion, he stated and wrote on the board: "All scientific laws [and] theories must be testable – capable of being proven wrong" (p. 6).

Conceptual ecologies

Endemic to this line of research is the assumption that the learner brings more with him than just a set of interconnected concepts representing formal knowledge. Granted, even if this were all that existed for a learner, analyses of learning and conceptual change would already be challenging. Adding to the complexity is the issue of all ideas, beliefs, emotions, and other extra-rational ideas which create a background upon which concepts are framed into. The grander scheme is comprised of both formal knowledge concepts and extra-rational ideas and beliefs and are all inclusively known as a conceptual ecology (Strike & Posner, 1992).

Given this complexity, it is necessary to describe the conceptual ecologies of each of the participants in this study. We offer brief descriptions of each conceptual ecology, resulting from the multiple qualitative probes and the analysis of their data.

Michelle

Michelle is quiet but attentive from the back of the classroom during discussions. During lab she is active and engaged, often asking questions of the instructors and working cooperatively with partners. In interviews she is quiet, but more outspoken than she tends to be in the classroom, taking time to ask about the specifics of natural phenomena (such as lightning, earthquakes, and the Sun) and also to describe to the researcher her enigmatic tastes in alternative music.

To summarize Michelle's conceptual ecology, the following points are made:

- Michelle has an affinity towards learning and she enjoys science and math: "I've always loved school. I love to learn" (Mi2, p.2). This attitude drives her to teach, although science is not a discipline that she feels necessary to place special emphasis upon in her teaching.

- She has a fascination with the natural world, especially when considering the possibility for disaster: "I don't want to get hit with some asteroid" (Mi6, p. 7). In a similar vein, Michelle sees the authority and validity in scientific knowledge in most all cases.
- Michelle is self-assured and displays confidence in her ideas, even when considering abstract concepts or tasks. She is thorough in her explanations during interviews, although she seldom extends a discussion beyond what is originally asked.

Jamie

Jamie is especially quiet – so much so that it was sometimes a worry that transcribing the details of her interview sessions would be problematic. However, Jamie's apparent reservedness was generally a misinterpretation of the long pauses she exhibited before speaking. Rather, Jamie showed great capacity to think about her own attitudes and conceptions and was generally eager to reflect upon such.

To summarize Jamie's conceptual ecology:

- While outwardly reserved, Jamie is thoughtful and displays a high capacity for learning: "Sometimes I just want to talk to some science guys and say, 'This is what I learned today, what do you think of this?'" (Ja7, p. 8)
- Reflecting on previous experiences with science (e.g., "We read from the book and answered questions. That's all we ever did" [Ja1, p. 4].), Jamie is eager to show science to her students in a more active way, similar to what was modeled during this physical science course.
- Jamie shows an especially clear religious conviction. Without explicit prompting for such, Jamie will refer to her own beliefs and the teachings of her church.

Laura

Of all the participants in this study, Laura was the least at ease with her responses to the interview probes. A typical and oft repeated response in the interviews was, "I don't know." Laura showed similar reserve in laboratories and in working with others. Even so, and surprising to us, Laura's grades in the class were actually higher than those of Jamie (though not as high as Michelle's or Joni's).

Highlighting some important aspects of Laura's conceptual ecology, we make the following summary:

- Laura shows low self-efficacy, is not sure of her own ideas, and looks for simple and brief answers rather than thinking through unfamiliar concepts.
- In previous experiences in high school and college, Laura has felt alienated from science curricula. She feels most comfortable with the notion of teaching geology lessons (as opposed to chemistry or biology lessons) in a future classroom, for these topics were more sensible to her in previous classes.
- Laura has a strong, but vague, religious conviction – she is not explicit about what her specific religious views are. She only notes that she is opposed to science that might "start [asserting] anything against God" (La2, p. 3).

Joni

Joni is outgoing and vibrant both in class and in interview sessions. Her capacity to think deeply is matched only by her willingness to communicate her thoughts. Joni is openly enthusiastic about class and about her participation in this research.

Some aspects of Joni's conceptual ecology to point out are as follows:

- Joni shows very high self-efficacy and metacognition, reflecting deeply about interview sessions (even after they transpire). She is very verbal and willing to consider issues at great length.

- “I think science is really fun and you can do a lot of things with it [in the classroom]” (JoQ1). Joni is not intimidated by science and is enthusiastic about teaching – in fact, emphasizing – it in her classroom.
- Joni has an especially explicit religious conviction. She will naturally and comfortably consider the teachings of her church and her beliefs in the context of a discussion of scientific knowledge.

Preliminary results: Sample of differences

The purpose of this study is to show how four very different learners can, each in their own way and as a result of each respective conceptual ecology, come to a similar set of inconsistent evaluations of science and science's way of knowing. Before we show this, we should point out just how different these learners' conceptions of science really are. This is summarized in Table 1.

Table 1:
Summary of case study comparisons

	Science definition	Science purpose	Science/religion interaction	Tentativeness
Michelle:	a process (limited), with emphasis on products	for utility (societal and disaster)	segregation	tentative historically
Jamie:	a process used towards producing knowledge	for explanation	segregation	tentative due to mistakes
Laura:	is knowledge and nature/world	vague	vague	non-tentative
Joni:	a process (limited), with emphasis on products	for utility (personal and health)	integration	tentative (as evidenced by personal beliefs)

Under “science definition” (i.e., how each case study participant describes and defines science itself), we see a variety of understandings. Related to this category is “science purpose” (what each learner describes the motives and purpose of science to be). Michelle overtly describes science as being a method of understanding the world, yet she emphasizes science's importance to be in what it can provide for humankind. She is specifically interested in how science can prevent large-scale disaster, such as asteroid collisions and earthquakes. Similarly, Joni describes the processes of science, yet emphasizes the things that science provides for us, especially towards medical advances. Laura most readily describes science as being “the earth and what it's made of” (La_Q1), focusing on the actual knowledge of science. Laura is less clear about what science is useful for, and tends to give only vague and limited responses to probes which ask about the motives of science. Jamie, unlike the others, was especially steadfast in paralleling “science” with “learning.” Using this analogy, she emphasized both the process and the knowledge of science, and consistently described science's primary purpose as being for explanation, rather than for application.

As interview probes were used, the issue of how religion and science interact was a consistently visited theme. This sometimes resulted from a few direct interview questions, but it is important to note that the idea of religion was more often something brought to light by the case study participants themselves. While Laura only suggested that interactions existed between science and religion, she did not specify exactly what these were. Michelle and Jamie generally tried to separate any knowings of science from those of religion, stating that they were different and not compatible in most circumstances. Joni, on the other hand, would often try to integrate the knowledge that she had of science and the religious beliefs which she held, showing how these both could be used to support one another.

One other comparison that can be made between the participants is how they viewed the tentative nature of scientific knowledge. As has been pointed out and researched (Lederman, 1992; Lederman & O'Malley, 1990), the idea that scientific knowledge changes is difficult for students and teachers to fully understand. In our learners, we found that each could, at one time or another, suggest that scientific knowledge changes. However, these "changes" had a variety of definitions. For example, Michelle noted that scientific knowledge changes, but that most of this changing has already taken place so that our scientific knowledge is no longer susceptible to variation. Jamie described the changes which science undergoes as a result of making mistakes in laboratories or in some other kind of procedure, similar to how a student learner might make a mistake in a laboratory. Joni most often referred to science being changeable when she reflected upon scientific ideas which did not correspond to a religious belief. In other words, knowledge which she did not agree with she expected would eventually change or somehow be more fallible. Laura, while sometimes implying that science's knowledge could change, largely stuck to a view which suggested knowledge is static.

This overview of our learners' conceptions is meant only to give the reader an understanding that the views which our participants exhibited were varied and complex. Not only did the individuals vary from one another, but they varied within the individual. For example, while Joni and Michelle each had similar definitions of science, they described other aspects of the NOS quite differently. There is no set pattern in terms of what NOS conceptions correspond to one another.

The Moon, the Big Bang, and the atom

What follows in this section is the primary data considered in our discussion. Three specific interview probes are described:

- An IAI asking about what the nature of the atom is and how science comes to such a description;
- A CI asking the participant how she would respond to a student who protests Big Bang theory; and
- A CI asking the participant how she would respond to a student who protests the idea that the Earth is round.

Each probe is stated approximately as it was posed to each learner. Following each probe description are the individual responses of each of the four learners. What we find intriguing (and, thus, what we follow up on in the discussion of this piece) is how consistent each of these learners is compared to one another, yet how inconsistent each learner is in portraying the nature of science.

PROBE A: *In class, Dr. Hemingway discussed electrostatic charge and the atom. What does the atom look like? How do we know what it looks like? (i.e., how are we able to "see" this?)*

Michelle: Michelle described the atom in greater detail than was covered during lecture, noting not only the electrons surrounding the atom, but also the protons and neutrons that make up its nucleus. When asked, "How do [we] know that that's right?" Michelle admits that she's thought about this, but that she does not know herself. She mentions that she knows that we could see some very small things, such as viruses, but that she does not think that atoms can be viewed in the same way. She does suggest that "maybe like observing the behavior of certain things, like static electricity" (Mi5, p. 6) would allow us to come to understand the atom. She admits that even though she does not really know exactly how science comes up with such knowledge, she never questions it, since (according to her) "people that are smarter than me have figured it out" (p. 7).

This description regarding the nature of the atom is interesting in that Michelle has no problem believing the picture that science portrays the atom to be, even though she admits that she only has some guesses, albeit very good ones, regarding how they could know anything about such a small and difficult-to-pin-down entity. Yet, probes in the following probe will show that Michelle is not as comfortable with and confident about other scientific theories.

Jamie: Jamie is confident and accurate in describing the structure of the atom, complete with protons and neutrons in the nucleus (of positive charge) and electrons (of negative charge) outside of this. Jamie states that the electrons are "orbiting" (Ja5, p. 12), as is often described, rather than in a more nebulous cloud, as was described in this class. But, this seems to be a minor discrepancy, especially realizing that Jamie has seen descriptions of the atom in other places before this course.

When asked how we know what the atom looks like, Jamie replies with a profound and honest, "Oh my" (Ja5, p. 12). She seems genuinely puzzled, and imagines that there must be some experiment that must be set up in order to determine atomic structure, but she does not know what it is. She wonders, skeptically, if we have any technology that would be able to see, directly, the structure of an atom but the researcher confirms for her that there is no such thing, due to limitations of light itself. So she resigns to the idea that "that's just the way it is" (p. 13), but does not hazzard to guess how or how well we know it. Still, she never questions the validity of the picture that was presented in class.

Laura: Unlike the other three case study participants, Laura is not able to recollect the description of the atom as it was presented in class. As the researcher re-describes it to her, at no point does she fill in any information on her own, nor does she suggest that any of it sounds familiar. Laura's only contribution to this picture is that "it's just tiny" (La5, p. 6).

Given her own statement that the atom is tiny, I ask Laura how it could be that we describe the different parts of the atom and their electric charges. Laura recalls a description in class regarding how there were early disagreements about the description of matter and the atom, and that she wonders herself how it is that one model can be ascertained over another. The best idea that she has is to determine "the smallest particle of the element" and then build the atom from there. Laura does not have any other explicit ideas about this, although she does not question whether or not the structure of the atom, as described in class, is correct. Such non-questioning is in line with the results of previous probes of Laura that suggest that the kind of science knowledge that is represented by science textbooks is unquestionable.

Joni: Joni is quite comfortable describing the structure of the atom, talking about not only what was discussed in class, but adding onto this picture her knowledge from chemistry courses of different electron subshells: "Some of them travel like in p-orbits and some of them travel in s-orbits" (Jo3, p. 10). It is interesting to note that she thinks of these orbits as being very rigid structures with very particular paths for the electrons, even though one sentence before she described the electrons as all belonging to a less structured "cloud," as was described to her by a physicist. It is notable that these two logically competing conceptions do not actually compete in her mind. Still, Joni's picture of the atom basically matches what is taught in this and in other science courses.

Asked how we could know what the atom looks like, Joni describes sending different particles through paper (presumably referring to Rutherford's gold foil) and observing how the particles scattered. And from an analysis "they [scientists] could kind of put it all together" to form our current description of the atom (Jo3, p. 10). Joni is not sure, but she does not think that we have actually viewed an atom directly, rather she thinks "it's more like a puzzle that they try to put together," but in putting it all together and with what they know about charge, she "think[s] that they're pretty accurate . . . even though they've never seen it" (p. 11). It is important to emphasize this last phrase of Joni's, suggesting that there is merit in scientific knowledge even when it does not rely on evidence that "they've [scientists] never seen." Joni's confidence in this picture of the atom and how it is inferred indirectly will be important to remember when we look to her responses to other probes.

PROBE B: *In your sixth grade classroom, you present a unit in astronomy in which you read about Big Bang theory, which describes the universe as having expanded out of a single point of matter and space around 12 billion years ago. One of your students protests, claiming that he was taught in church that the Earth is 6,000 years old, and that was created in a much more deliberate fashion.*

Michelle: Two critical incidents dealt with what science "knows," and the possibility of such knowledge being challenged by students in the classroom. In this first case, it is suggested that a sixth grader would question the idea of Big Bang theory as it was presented in a text by stating that, "but, in church they tell me that the Earth, and everything else, was created 6000 years ago." Michelle gives the following measured response:

> Hmmm. Um . . . I don't know, I'd probably say that . . . I don't know, something like, 'that view is . . . okay too; [but] right now we're learning about science and this is what science says. . . . but I'm certainly not trying to . . . discredit whatever you might believe' (Mi6, p. 3).

Two points can be made here. First, when Michelle tells her student that "we're learning about science," she is referring to science as a body of knowledge, rather than a way of knowing. Second, Michelle wants to be respectful of a student's beliefs, and states that she would not want to address the issue any further. "I'd probably stay clear of it" (p. 4), rather than making any further distinction between the knowledge of a science book and the belief of any individual student. When pressed, Michelle even suggests that she would try to de-emphasize such topics, only to "maybe just sort of go over it quickly" (p. 4).

Jamie: Critical incidents that deal with knowledge are more complicated for Jamie, and she does not have as straightforward solutions to these as she did with other CI probes. For the student who protests the notion of the Big Bang, Jamie's first comment is that she would agree with him. Given a bit more thought, Jamie suggests that she "would have to give support [of] both and let the student decide which to believe" (Ja6, p. 5). She justifies this by noting that a teacher should not be biased, and that some students will be coming to class with their own beliefs that she would not want to argue with – especially, presumably, if she already agrees with them. While it is explicitly stated that she is teaching an astronomy unit, Jamie sees merit in presenting a scientific view in comparison to a religious view – even though she states explicitly in other probes that the two ways of knowing are not comparable.

Laura: Described to Laura is the situation in which a student protests to the Big Bang explanation for the origin of the universe, in light of what the student was taught in church. Laura is genuinely perplexed about what to do, laughing to herself: "I have no idea, I'm trying to think but I have no idea what I would do" (p. 2). As we acknowledge that this is certainly a difficult situation, Laura clarifies that teaching in a "public [school] where everyone believes different things" (p. 3) is going to make dealing with such an issue more problematic. Through other probes it has become evident that Laura does not have a firm grasp of how science produces its knowledge, so, without such a concept readily at hand (in addition to not having knowledge regarding Big Bang theory), Laura has no means of producing a solution to this dilemma.

Joni: "Oh, that is so hard," (Jo5, p. 5) Joni exclaims in response to the possibility that a student has a problem with the idea that the universe is billions of years old and formed via the Big Bang, rather than being divinely created 6000 years ago. "I've found myself in that situation, and I want to raise my hand and say, 'well what *really* happens?'" Joni wants to accommodate this student's belief system, as she would with any student, but is especially inclined to do so since it corresponds to her own beliefs so well. She would make sure that the student realized that this belief was okay, and that science did not have the ultimate say in all matters:

> I'd just tell them that there's, that just because it's a theory, it's not a fact yet, but it's been tested for a long time, but in a way that it could fit together with their church. [They can] believe how they believed, and they could take the knowledge that was in the book as they wanted to take it. There's no one forcing them to believe in the theory of the Big Bang (Jo5, p. 5).

Joni's personal tactic of integrating her knowledge of science with her religious beliefs is something she advocates for others as well. This is not so surprising in light of other probes. What is surprising is that Joni describes Big Bang as "a theory, [but] it's not a fact yet," suggesting that theories are these speculative and not well understood or important facets of science. While this is a relatively typical view, it is not the view that Joni suggests in other probes. The different views may be the result of Joni's consideration of herself in a teaching situation, or the result of the specific content of each probe.

Joni may simply be combining her notion of a tentative basis for scientific knowledge along with a belief system that is less accepting of certain pieces of that scientific knowledge. Even if this is the case, it should still be noted that Joni does not address any of the scientific evidence that may be behind the Big Bang theory, as she would for some other scientific theory (e.g., the structure of the atom).

PROBE C: *In the same astronomy unit, another student proclaims her father knows that the Earth is flat, and that all of the NASA missions are part of a government hoax.*

Michelle: Considering the same classroom as before, we imagine the scenario in which, when teaching about NASA missions to the Moon, a student suggests that, according to her father, all such missions were a hoax, and that the Earth is really flat. Michelle is disturbed that such a notion could exist:

> It would really bother me that she would think that, because, that just seems really, um, like in the Dark Ages or something. I'd want to open her eyes. It would really bother me that she felt like that, but I don't know how I would go about trying [to sway her beliefs] . . . maybe show some pictures of what it looks like when something's videotaping the Earth . . . (Mi6, p. 4)

Michelle, like the other case studies, is disturbed with some conceptions of students, but not with others. While it is probably relatively common for someone to believe in the reality of lunar landings, but not so much in the reality of a Big Bang, Michelle seems to miss the fact that the same scientific process that rationalizes a spherical planet also suggests a Big Bang. While these two incidents are presented to Michelle one after the other, she makes no apparent consideration that the two scenarios are, indeed, quite similar. Rather, Michelle focuses on the scientific content rather than the way that science generates such knowledge, and how this knowledge is different from other ways of knowing.

Jamie: In addressing the issue brought up by a student who claims that the Apollo missions were a hoax and that the Earth is really a flat body, Jamie begins in similar fashion as before. "Again, I'd have to respect her beliefs" (Ja6, p. 6). However, she immediately begins tackling this issue in a much different manner than she did with the Big Bang incident. She suggests that she would talk to this girl's father and try to understand his views more clearly. The intent here is to be able to better address this student's conception about the Earth and the Moon so that she could better understand how to teach her.

> Perhaps, eventually down the line this . . . [lesson] could interest this girl into joining the NASA program and finding out for herself . . . I'd end up saying, 'that's an interesting view, I've never heard of that before. Let me tell you what I know . . . and you could call the NASA people.' [And possibly we could] turn this into a science project (Ja6, p. 7).

So, even though Jamie really does want to respect all points of view, there are some that she is more adamant about trying to change. This in and of itself may not be surprising, yet what might be more troubling is the fact that Jamie does not recognize that she is treating two very similar problems (teaching Big Bang theory versus teaching Moon/Earth relations) with very different solutions.

Laura: Considering a student challenging the idea that the Earth is round and that NASA has ever sent missions to the Moon, Laura has a more concrete solution:

> Just pretend. Just go along with what I say [laughing]. I don't know. Um, no, I couldn't say that. . . But I know I've had teachers when there's that situation: 'Just learn this,' you know, 'It's what I'm supposed to teach you,' and things. I don't know what else you could do, if you've been taught the other way (La6, p. 3).

Laura is still at a loss with this situation, as she was with the Big Bang situation. But, in this case she suggests that a teacher can still go along with a particular lesson and ask the student to "just learn this" without letting it challenge his beliefs. Laura makes it clear that she does not want to challenge the beliefs of a student, yet she still emphasizes that this particular content needs to be taught without any modification, justifying this with a vague acknowledgment that the Apollo missions have a certain importance that needs to be explained. Noting that there is an importance to these events, Laura does not mention that these hypothetical events are in question by this particular student just as the Big Bang was put into question by another student. Laura does not compare her solution to this critical incident to that of the Big Bang. If she is not aware of how science has produced its knowledge and how this compares with how her hypothetical student has produced his knowledge, it seems that she has no solution to the problem at hand.

Joni: Joni was particularly responsive to these critical incidents, and it was enjoyable to watch her reactions to these classroom possibilities. Joni even referred back to these probes after this particular interview session was long over, both during subsequent interview sessions as well as in conversation outside of class and interviews. More so than any other probe, Joni seemed to be very reflective about the dilemmas posed in the two CI probes, especially this latter one. (Even on the exit questionnaire several weeks later she notes: "The Moon thing had me worried for days!" (JoQ2).) This is impressive because Joni was already very reflective and thoughtful to begin with, and even more so as a result of these particular critical incidents.

The idea that a student would believe that the Earth is flat and that the NASA missions were all hoaxes is very bizarre to Joni. However, it is something that she tries to address with some explicit ideas, suggesting that mathematics, analogies, and personal experience could all help a student better understand the idea that we can actually travel from a spherical Earth to our spherical neighbor, the Moon:

> I guess it's in mathematical formulas, and when you go step by step and show them exactly how things worked out and it comes out in the end product, you know, then that kind of [pause]; I think that math and science really works [sic] well together to prove things (Jo5, p. 8).

Ironically, an astronomer describing the Big Bang theory (a topic we had discussed just few minutes before Joni made this statement) probably could have made a similar argument. This is something that Joni never acknowledges. She continues with some other ideas:

> Someone could tell me that England is there, and I could see the truth in England. You know like little pictures of England and I could see some of it . . . And then [ask], 'well, do you believe in England?' And then they'll say, 'well, yeah.' And then you say, 'well have you ever been there?' . . . Well, Janie over here's been there, so do you believe [her]? (Jo5, pp. 5-6)

Joni makes a detailed argument using the England analogy and then extending it to the testimonials that astronauts could provide. "[I'll] just show them different things like that, and hopefully they'll have to believe" (Jo5, p. 6). She is adamant about getting this concept across, because it is connected to so many other ideas in science that she would be teaching. ("If they don't believe that we've really been to the Moon or that I know the truth about the Moon, then they're not going to care what I say the rest of the time" [p. 10].) Scientists would likely make the same point for Big Bang theory, describing how this concept is an explanation that unites multiple pieces of evidence and explanations in astronomy.

Discussion

We argue that the comparison of the responses to these three probes shows an important aspect of NOS concept understanding and the interaction that these conceptions have with "intuitive knowledge" (West & Pines, 1985, p. 2), or beliefs – those concepts that we may not have been formally taught, yet we utilize them to interpret our surroundings and our interactions. Such intuitions or beliefs are an integral part of learners' conceptual ecologies, and thus should play a pivotal role in conceptual change (Strike & Posner, 1992). Furthermore, beliefs are understood to be a subjective way of knowing, rather than an empirically based way of knowing. They are considered to be personal truths as opposed to absolute truths about the world (Smith, Siegel, & McInerney, 1995). As such, these "personal truths" are not held to the same epistemic criteria as scientific knowledge. Instead, beliefs can be extra-rational – meaning that they are not based on evaluation of empirical evidence – thus they may have little correspondence with the outside world. They are subjective, and they are often intertwined with affect.

Specifically, during the course of the study and its three selected probes, it became apparent that a learner's description of inferred theoretical knowledge (that is, knowledge that is "theoretical" in that science's description of that knowledge cannot be seen firsthand) could vary significantly, based on the learner's personal conception of and feelings regarding science's description. In addition to the fact that each of the three probes refers to scientific knowledge which cannot be directly observed, every case study participant had different kinds of responses for each of these probes, and there was a certain level of consistency between the case studies in how each probe was dealt with.

When asked about the structure of the atom, each learner except for Laura could describe confidently and relatively correctly (according to the description given in class) what this structure was supposed to be. Even Laura, when the structure was described to her during the interview, did not have any reservation about such a description. However, only one of the four learners (Joni) can make any specific description regarding *how* we have come to this description of the atom. Joni refers to Rutherford's scattering of particles off of the atom in order to piece together a kind of puzzle which then describes the atom's structure. But, Joni admits that she does not think that we have ever been able to view the atom's structure directly. Michelle imagines that the atom's structure must be understood by analyzing electric charges (specifically by "smarter people"), and Jamie suggests that experiments must be used to deduce the structure of the atom, even if we cannot see it directly. Laura is not sure of how we could describe the atom's structure, but neither was she sure of the atom's description itself.

In all cases in which the learners could describe the structure of the atom, they felt confident that this description was correct and was a match of the reality of the situation. At the same time, they could acknowledge or accept the fact that the atom has never been seen directly, except only by inferential means. In this case, a theory (specifically, the model of the atom) that had been constructed by scientific evidence and induction was completely acceptable to these three case study participants, and it was not contested by the fourth participant, Laura. What we make of all of this is that these learners could not only conceptualize a very theoretical idea, but also believe in it on a personal level, accepting it as "the truth."

In the critical incidents probes, however, the situation of a student protesting Big Bang theory comes up. As they did with the structure-of-the-atom probe, all of the respondents have similar reactions to the given situation. However, it is important to note that the common reaction to the Big Bang is much different than it is for atomic theory. In all of these cases it is acknowledged by each of the participants that having a belief different from Big Bang theory is perfectly acceptable. And, given this justification, the teachers-to-be suggest that multiple perspectives could be allowed in the context of a science lesson via one route or another. For Michelle, she would try to de-emphasize Big Bang theory altogether in anticipation of such a protest. Jamie could allow the inclusion of the alternate belief in the classroom as another acceptable alternative in this science lesson. Laura notes that it would be difficult to teach Big Bang theory at all, since everyone believes different things that should not necessarily be discounted. And Joni would suggest to her student that the idea of a Big Bang is "just a theory, not a fact yet."

Again, we find that, despite very different conceptual ecologies and conceptual frameworks, there is some consistency across the cases for one particular probe. All of the case study participants, while seeming to recognize that Big Bang theory is a part of science, would elect to de-emphasize such a theory in the classroom. Each hinted that, for them personally, they would tend to agree with a student's protest to this theory. Joni summed up some of the outward justification for this, suggesting that the Big Bang, being "just a theory," is not something that has direct evidence in its support. Yet, Joni and the other learners recognized the same attribute for the model of the atom, yet they felt very sure that such a description was accurate. What we find is that these students can be completely accepting of an inferred theory in one case (atomic theory) but not the other (Big Bang theory). They evaluate the meaning of "theory" differently according to their extra-rational interpretations. Moreover, these learners make no suggestion that they are aware of the fact that they are coming up with such different evaluations. The extra-rational evaluations are done automatically.

To further contrast how these learners compare scientific descriptions and their validity, the other critical incident for science knowledge can be analyzed: The "round Earth" CI. Again, in each case study a classroom situation was considered in which a student protested a particular part of an astronomy curriculum, in this case protesting that the Earth is round and that it is possible for one to travel to the Moon. While this probe immediately followed (by a matter of seconds) the Big Bang probe, all of the learners treated this situation with a distinctly different strategy than they did the previous situation involving the Big Bang. They each acknowledged, again, that different beliefs are something that one would have to deal with in any classroom, but they then went on to describe how it might be possible to change such a belief or make the student at least see the reasoning of the scientific perspective. For Michelle, the flat Earth view would "really bother" her, and she would want it to be changed. Jamie would suggest that the student could go through a series of intervening experiences that could possibly even turn the student around to see the scientific perspective and, in turn, make a scientist out of the student. Laura would tell students to "just learn this" as something that would be important to learn, although not necessarily believe, intuitively acknowledging the distinction between understanding of a concept and acceptance of that concept (Southerland, Sinatra, & Matthews, in press). It is important to note that Laura did not suggest that it is appropriate to convince a student to learn Big Bang theory in the previous probe. Finally, Joni, going at great lengths to solve this apparent problem, devises analogies and evidence that could be used to try to convince a student that the Earth is round and that NASA missions to the Moon are possible – thus acknowledging the importance of the scientific knowledge of this concept in direct contrast to her position on the Big Bang theory.

Again, these learners are acting as advocates of scientific knowledge and science's way of knowing only in select cases. Extra-rational evaluations, again, come into play, and again, the learners make no suggestion that they are aware of the fact that such evaluation takes place. No matter how well or poorly any of the case study learners can explicitly describe the nature of science and the sub-concepts that are required for an understanding of the nature of science, these data demonstrate that each of the four learners elects to value certain scientific knowledge over other scientific knowledge. This selectivity is based not on how directly observable the phenomenon happens to be – for none of these pieces of scientific knowledge are directly observed by any of these learners – but instead on some other evaluation that each learner does on her own.

Conclusion

The implications of these results are plentiful. First, this research further reinforces the idea that what is taught explicitly is not always directly translated into learning. This is no surprise, given the general tenets of constructivism and conceptual change theory. Second, these results speak to conceptual change research, demonstrating that concepts and conceptual change are not cold and isolated, but instead interact with a learner's emotions, values, and other aspects of a conceptual ecology (Dole & Sinatra, 1998; Pintrich et al., 1993; Strike & Posner, 1992). Finally, our study has a specific message for research in NOS understandings: that these concepts are deeply connected to and interactive with a learner's values and emotional commitments.

At issue in this research is not so much the conceptions that the learners exhibit, but *how* they justify such conceptions or stated ideas. In fact, it is clear from our research that to speak of "conceptions" regarding the NOS may not be a supportable idea. Rather, we see that learners seem to exhibit intuitions or vague notions about what "science" is, but these are only beginnings of descriptions. From these beginnings, learners can create a variety of explanations and descriptions of what the nature of science is and how to present it in the classroom. This implies that a direction for future research would be to look at the prospect of phenomenological primitives, or p-prims (diSessa, 1993), and how such knowledge structures could be used to describe the beginnings of NOS conceptions. At this point, our research only implicates p-prims or some similar knowledge structure, but does not offer empirical support for such a claim. More research in this direction should be conducted.

More importantly, our research shows how extra-rational evaluations can dominate the conceptual ecology, overruling other evaluations that may be more empirically based. While a specific NOS conception shows up in some cases (such as the idea that explanations in science can be inferred indirectly rather than observed directly), it is not consistently adhered to. The learner evaluates situations on a case-by-case basis, utilizing not only what she has learned about science and science ideas, but also what she feels about a particular aspect of science. Again, we suggest that more research in this direction needs to take place, for the literature which currently describes NOS learning tends to focus on more rational influences on learning and conceptual change. We argue that the classroom and our world are not insulated from emotions and intuitions. Both teachers and students – even those who may understand NOS well enough to describe it in a straightforward manner – are human. As humans, we feel and react to such feelings.

Conceptual change, it has been argued, is not necessarily a rational event (Southerland, 1997; Strike & Posner, 1992), just as Kuhn (1970) and other philosophers of science have described large changes in scientific theory to not necessarily be triggered by entirely logical, deductive processes. Humans are much more elaborate and complex in their thought processes than simple logical and rational thinking can allow. Thus, we fall in love, we change our minds "just because," and sometimes we eat that cookie found on the floor. Even when there are not scientific, logical reasons for one's actions and ideas, an individual can still find certain actions reasonable, though he or she may not be able to explicitly describe the reasons. We argue that the extra-rational evaluations exhibited by our case study participants suggest the nature of understanding NOS ideas is even more complicated than previously imagined. While it is clear that explicit and focused instruction of NOS tenets is necessary, we contend that it is also necessary for a learner to identify (and, thus, for instruction to assist in this process) more clearly not only her conceptions, but also her extra-rational evaluations.

REFERENCES

AAAS. (1990). *Science for all americans: Project 2061*. New York: Oxford University Press.

AAAS. (1993). *Benchmarks for science literacy*. New York, NY: Oxford University Press.

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

Abd-El-Khalick, F. S., & Lederman, N. G. (1998, April). *Improving science teachers' conception of the nature of science: A critical review of the literature.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Diego, CA.

Abell, S. K., & Smith, D. C. (1994). What is science?: Preservice elementary teachers' conceptions of the nature of science. *International Journal of Science Education, 16*(4), 475-487.

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

Akerson, V. L., & Abd-El-Khalick, F. S. (2000, April 28 - May 1). *The influence of conceptual change teaching in improving preservice teachers' conceptions of nature of science.* Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, New Orleans, LA.

Chi, M. T. H., & Slotta, J. D. (1993). The ontological coherence of intuitive physics. *Cognition and Instruction, 10*(2 & 3), 249-260.

Demastes-Southerland, S., Good, R., & Peebles, P. (1995). Students' conceptual ecologies and the process of conceptual change in evolution. *Science Education, 79*(6), 637-666.

diSessa, A. A. (1993). Towards an epistemology of physics. *Cognition and Instruction, 10*(2 & 3), 105-225.

Dole, J., & Sinatra, G. (1998). Reconceptualizing change in the cognitive construction of knowledge. *Educational Psychologist*, *33*(2/3), 109-128.

Gess-Newsome, J. (1999). Secondary teachers' knowledge and beliefs about subject matter and its impact on instruction. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 51-94). Dordrecht, The Netherlands: Kluwer Publishing.

Gess-Newsome, J., Southerland, S. A., & Johnston, A. T. (2000, January). *Translation of teachers' views to students' understandings of the nature of science: Examining a reform based college science course.* Paper presented at the annual meeting of the Association for the Education of Teachers in Science, Akron, OH.

Guba, E. G. (1990). Subjectivity and objectivity. In E. W. Eisner & A. Peshkin (Eds.), *Qualitative inquiry in education: The continuing debate* (pp. 74-91). New York: Teachers College Press.

Hewson, P., & Hewson, M. (1989). Analysis and use of a task for identifying conceptions of teaching science. *Journal of Education for Teaching, 15*(13), 191-209.

Johnston, A. T. (2001). *A conceptual change analysis of nature of science conceptions: The deep roots and entangled vines of a conceptual ecology.* Unpublished doctoral dissertation, University of Utah, Salt Lake City.

Johnston, A. T., & Southerland, S. A. (2000, April). *A reconsideration of science misconceptions using ontological categories.* Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, New Orleans, LA.

Kuhn, T. (1970). *The structure of scientific revolutions* (2nd ed.). Chicago: University of Chicago Press.

LeCompte, M. D., & Preissle, J. (1993). *Ethnography and qualitative design in educational research* (2nd ed.). San Diego, CA: Academic Press.
Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching, 29*(4), 331-359.
Lederman, N. G. (1998). The state of science education: Subject matter without content. *Electronic Journal of Science Education, 3*(2), 1-12.
Lederman, N. G., & O'Malley, M. (1990). Students' perceptions of tentativeness in science: Development, use, and sources of change. *Science Education, 74*(2), 225-239.
Lederman, N. G., Schwartz, R. S., Abd-El-Khalick, F., & Bell, R. L. (1999, March). *Preservice teachers and their nature of science instruction: Factors that facilitate success.* Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Boston, MA.
Loving, C. C., & Foster, A. (2000). The religion-in-the-science-classroom issue: Seeking graduate student conceptual change. *Science Education, 84*(4), 445-468.
Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd ed.). Thousand Oaks, CA: Sage Publications.
National Research Council. (1995). *National science education standards*. Washington, D.C.: National Academy Press.
National Science Teachers Association. (2000). Nsta position statement: The nature of science. *NSTA Reports!*(May/June), 15.
Nott, M., & Wellington, J. (1998). Eliciting, interpreting and developing teachers' understandings of the nature of science. *Science & Education, 7*(6), 579-594.
Novak, J. D., Mintzes, J. J., & Wandersee, J. H. (2000). Learning, teaching, and assessment: A human constructivist perspective. In J. J. Mintzes & J. H. Wandersee & J. D. Novak (Eds.), *Assessing science understanding: A human constructivist view* (pp. 1-13). San Diego: Academic Press.
Pintrich, P., Marx, R., & Boyle, R. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 63*(2), 167-199.
Poole, M. (1996). "...For more and better religious education". *Science & Education, 5*(2), 165-174.
Posner, G., Strike, K., Hewson, P., & Gertzog, W. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211-227.
Richardson, L. (2000). Writing: A method of inquiry. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (2nd ed., pp. 923-948). Thousand Oaks, CA: Sage Publications.
Rubba, P., & Anderson, H. (1978). Development of an instrument to assess secondary school students' understanding of the nature of scientific knowledge. *Science Education, 62*(4), 449-458.
Ryan, G. W., & Bernard, H. R. (2000). Data management and analysis methods. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (2nd ed., pp. 769-802). Thousand Oaks, CA: Sage Publications.
Smith, M. U., Siegel, H., & McInerney, J. D. (1995). Foundational issues in evolution education. *Science & Education, 4*(1), 23-46.
Southerland, S. (1997). *Conceptual change theory and what counts as science learning: Or how much more white guy can we get?* Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Chicago, IL.
Southerland, S. A. (2000). Epistemic universalism and the shortcomings of curricular multicultural science education. *Science & Education, 9*, 289-307.
Southerland, S. A., & Gess-Newsome, J. (1999). Preservice teachers' views of inclusive science teaching as shaped by images of teaching, learning, and knowledge. *Science Education, 83*(2), 131-150.
Southerland, S. A., Sinatra, G. M., & Matthews, M. (in press). Knowledge, belief, and science education. *Review of Educational Psychology*.

Southerland, S. A., Smith, M. U., & Cummins, C. L. (2000). "What do you mean by that?" Using structured interviews to assess science understanding. In J. J. Mintzes & J. H. Wandersee & J. P. Novak (Eds.), *Assessing science understanding: A human constructivist view* (pp. 72-95). San Diego, CA: Academic Press.

Strauss, A., & Corbin, J. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory* (2nd ed.). Newbury Park, CA: Sage Publications, Inc.

Strike, K. A., & Posner, G. J. (1985). A conceptual change view of learning and understanding, *Cognitive structure and conceptual change* (pp. 211-232). Orlando, FL: Academic Press.

Strike, K. A., & Posner, G. J. (1992). A revisionist theory of conceptual change. In Dushl & Hamilton (Eds.), *Philosophy of science, cognitive psychology, and educational theory and practice* (pp. 147-176). Albany, NY: State University of New York Press.

Tyson, L. M., Venville, G. J., Harrison, A. G., & Treagust, D. F. (1997). A multidimensional framework for interpreting conceptual change events in the classroom. *Science Education*, *81*(4), 387-404.

Venville, G. J., & Treagust, D. F. (1998). Exploring conceptual change in genetics using a multidimensional interpretive framework. *Journal of Research in Science Teaching, 35*(9), 1031-1055.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Learning and Instruction*, *4*, 45-69.