Tiny atoms, round planets, and big bangs:
Extrarational constructions of the nature of science

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Extrarational Evaluations of the Nature of Science

ABSTRACT

This research considers how learners conceptualize nature of science ideas. 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 employ could change radically as a result of differing situations and research probes, especially when extrarational factors (emotions, values, etc.) were evoked in the learner. Our findings suggest that conceptual change theory needs to further address the interaction of extrarational 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.
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 trying to teach concepts regarding the nature of science (NOS), we find ourselves pushing these teachers-to-be to converse as philosophers, albeit on an elementary level. It should not be too surprising, then, that understanding the NOS is difficult (e.g., Lederman, 1992). A reason for this lies in the fact that the concepts of NOS are so complex, being largely philosophical and based on multiple abstract ideas rather than singular concrete physical actions or objects (Johnston & Southerland, 2000). Further, 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.

As has been described (Abd-El-Khalick, Bell, & Lederman, 1998; Gess-Newsome, 2002), typical science instruction seldom explicitly addresses NOS concepts in classroom settings, even though NOS concepts are not effectively learned via implicit treatment in a curriculum. Perhaps because they are difficult concepts to negotiate and learn, teachers at all levels have a tendency not to teach them in their 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 as well as into greater society.
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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. Such considerations could naturally have deep interaction with a learner’s personal beliefs, motivations, and attitudes – those things that lie beyond the realm of logical, rational thinking and so are more deeply influenced by what we call extrarational factors. As Poole describes (1995), our personal, societal, and cultural values shape how we understand the world around us; and in fact, these values actually define what the nature of science is. The NOS is not a concept which exists independent of humanity, society, and cognition. The NOS is a set of concepts constructed and defined by a community with intrinsic values, and these values shape what we hold the NOS to be. What makes this so intriguing for research in learning is that, being such a value laden and constructed concept, individual learners are likely to employ their own set of values and subsequent constructions (dependent upon these values) as they learn about science and its nature. It is this issue that we highlight in this paper: Due to (rather than in spite of) the fact that learners are actively thinking and evaluating and constructing, they produce NOS meanings that can often be much different that those which we may be trying to teach. Vonnegut, as quoted above, calls this "disruptive;" we, as researchers, find this fascinating.

Background

In science education, research of conceptual change and alternative conceptions and research analyzing 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 conceptions within the nature of science relevant to the idea of science as a 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 methods (Poole, 1996; Southerland, 2000).
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 extrarational 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 reemphasize 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 extrarational.

It is well documented that NOS conceptions have been difficult for students and teachers to fully understand (e.g., Abd-El-Khalick et al., 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 et al., 1998; Gess-Newsome, in press; Lederman, Schwartz, Abd-El-Khalick, & Bell, 1999), encourages learners to be aware
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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 in 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). Previous research has also documented that our best understandings of the conceptions that learners do hold are best illuminated with the use of qualitative measures, including open-ended questions and interviews (Lederman, Wade, & Bell, 1998).

What is less well documented is why NOS concepts are so elusive for learners in the first place. Why does the instruction of these concepts require such deliberate attention? Surely, part of the answer to this question involves how these concepts are imbedded within the 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). This contention calls into play research focusing on conceptual change theory. While much more articulated than it was two decades ago, conceptual change theory still has far to go to fully describe the cognitive processes and structures utilized in replacing one concept with another. Thus, the central emphasis of our work was 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.

Methods

The premise of this research was that NOS conceptions should be studied in depth in a small number of learners to understand more about where their NOS conceptions come from and how they develop and change. Towards this end, four preservice elementary teachers' conceptions regarding the nature of science were studied during the course of a semester. To fully understand the development of these learners' NOS conceptions, we describe the context of the study and its procedure.
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The scene

The participants of this study were students of a science course co-offered by the physics and chemistry departments of Bonneville State University, 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.

This class had a novel approach, exhibiting a balance between instruction on science content, instruction on the nature of science, and modeling methods for potential 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, 1998; Gess-Newsome, 1999; Lederman, 1998; Lederman, 1999).

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. 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]).
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Although this course did not emphasize NOS concepts as much as these other studied courses have, in our estimation the emphasis that did exist on NOS concepts was explicit and deliberate. Moreover, these concepts were addressed early in the course, before most of the interview probes were used; and the interview probes (described in a subsequent section) provided the opportunity for learners to explicitly reflect on their own NOS conceptions, as advocated by the research of Akerson and colleagues (Akerson et al., 2000). Finally, also promoted by Akerson et al. (2000), the context of NOS instruction of this course was imbedded into the context of science content instruction. Such an approach, it is argued, should prove more authentic and effective than when NOS concepts are taught without connection to the science content.

It was for these reasons that, despite the recognition that conceptual changes in NOS are difficult to come by, we expected at least moderate gains in student NOS understandings so that students would exhibit some informed views of NOS. Our purpose was not necessarily to show how a particular intervention effected a particular set of newly informed NOS concepts, but to describe how any particular set of NOS understandings could interact with a learner’s conceptual ecology, as has been suggested for other concepts by the conceptual change literature (Strike & Posner, 1992).

The cast

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, not officially accepted into 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. Students were typically “traditional” in the sense that they entered college immediately after high school. 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
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classroom practice and pedagogy. Many students enrolled in this course because, in addition to satisfying general education and major coursework, it was considered preferable to other courses in physics, chemistry, the life sciences, etc.

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 and was later used as part of the data analysis.

Case study selection

The case studies were meant to study preservice elementary teachers' NOS conceptions undergoing development and change. 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.

Four case study participants were selected for this research. A necessity of this research, this relatively
small sample size was used in order that each learner’s NOS conceptions could be more thoroughly
investigated via qualitative interview probes and classroom observations. To select participants, a survey
asking for demographic information was utilized. 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 exhibited both the potential to gain in their NOS understandings
from this course and some differences in their original conceptions.

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 involving 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. Finally, all
participants were observed in class and in laboratory so that their participation in class and interaction with
NOS ideas could be documented.

The majority of the data for these case studies were produced using multiple qualitative probes. These
probes were based on a variety of interview techniques, including 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,” or “CI,” in which the learner is asked about a potential classroom situation in which she is the
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While the data which were collected were part of a larger project (Johnston, 2001), it became apparent that specific probes elicited conceptions of learners that were comparable. Specifically, three probes were focused on:

- 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.

Although 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 elicit several different aspects of each learner's conceptual ecology.

Data analysis

The data analysis of this study utilized the constant comparative method of analysis, also known as grounded theory (Strauss & Corbin, 1998). The data were analyzed in three distinct levels with each level being viewed as a new set of filters and tests of the tentative meanings generated through the analysis. That is, each level 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 one participant'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
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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 representing one of these stages.) This compilation of data for each of the four participants was documented in a table. 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 during that stage. (For other examples of this kind of coding, see Loving & Foster, 2000; Tyson, Venville, Harrison, & Treagust, 1997; Venville & Treagust, 1998). These tables simply allowed the researcher to have a snapshot of each learner’s conception and a way to compare these at a given point in time to another.

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 then 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
Results

This research focuses on the interaction between a learner’s conceptual ecology with the learner’s NOS conceptions. We present, first, the general conceptual ecologies of the learners participating in these case studies, followed by a brief comparison of some of their actual NOS conceptions. This is followed by a more thorough description of specific NOS conceptions interacting with conceptual ecologies in each of the four learners, as reflected by the three probes describe above.

Conceptual ecologies

Endemic to this line of research is the assumption that the learner brings more with him/her than just a set of interconnected concepts representing formal knowledge. Granted, even if this formal knowledge were all that existed for a learner, analyses of learning and conceptual change would still be challenging. Adding to the complexity is the issue of all ideas, beliefs, emotions, and other extrarational ideas which create a background upon which concepts are framed into. The grander scheme is comprised of both formal knowledge concepts and extrarational 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.

Michelle. On a typical day, Michelle will quietly walk into class with a cup of hot chocolate in her hand and a backpack over her shoulder, taking her seat towards the back of the classroom and drawing little attention to herself. 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:

been tested and verified (Strauss & Corbin, 1998).
• 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 impossible. However, to conclude that Jamie was disengaged or simply shy would have been a misinterpretation of the long pauses she exhibited before speaking. Indeed, Jamie showed great capacity to think about her own attitudes and conceptions and was generally eager to reflect upon such. In class, Jamie drew almost no attention to herself, although she remained engaged in class and active in lab.

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
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, even if religion is not explicitly introduced by the research probe. The following transcript of data shows this especially clearly:

Well, to me . . . religion is more important than science . . . But I think it's important and I think it's great and I think that science has everything to do with religion in the way that I believe that someday I'll be making worlds – because if I'm righteous enough and if I'm good enough that someday I'll be like God and I'll be able to do it. And . . . I believe that he uses scientific laws. So someday, I'm going to have to know all of them, and so as much as I can learn here – great. 'Cause I don't have to learn as much up there. So, um, to me, science is part of religion [and] if you base everything on science and no religion then I think that . . . my priorities would be not where they should be (Jo6, p. 5).

Conceptual ecologies influencing NOS conceptions

From the above descriptions of the four conceptual ecologies at hand, one gets the impression that (not surprisingly) we are considering four unique learners with unique backgrounds and unique lenses through which to perceive the world. Our first set of results shows how these unique conceptual ecologies promote unique NOS conceptions in each of the four learners. Results in the subsequent section will show how similarities in conceptual ecologies in turn produce similar interpretations of science.

Table 1 highlights the four learners and four specific conceptions of the NOS which were probed for. "Science definition" is the concept of how each case study participant describes and defines science itself. Related to this is "science purpose," the concept of what science's motivations, values, and purpose are according to each learner. "Science/religion interaction" is the concept of how these two ways of knowing relate to and interact with one another. Finally, "tentativeness" is the concept of how science changes, both in
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degree and in method. For example, scientific knowledge could be viewed to not change or to change dramatically; and, a change in scientific knowledge could be thought to be caused by error, by advances in technology, due to the limits of knowledge itself, etc.

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“Science definition” and “science purpose” are very related to one another and to each learner's conceptual ecology. 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 and the natural world itself. 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. It is important to note that the idea of religion was typically something brought to light by the case study participants themselves, only in a few instances was this issue introduced by the researcher. The religious values and beliefs of these learners were quite apparent and influential in their conceptions, especially as they discussed pieces of scientific knowledge they viewed as controversial. (This is more dramatically emphasized in the following section.) For example, Laura subtly suggested that interactions existed between
science and religion, but 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.

The conception of science's tentative nature was surprisingly fluid between learners. As has been pointed out (Lederman, 1992; Lederman & O'Malley, 1990), the idea that scientific knowledge changes is difficult for students and teachers to fully understand. In our study, 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.

Much interest lies in each of these conceptions of aspects of the NOS, and more analysis of how these concepts develop has been researched and discussed (Johnston, 2001). Of more concern for our present purposes, this overview of our learners' conceptions demonstrates the rich variety of NOS conceptions that can be had, both as individual concepts and as a matrix of intertwined ideas. For example, the table shows a variety of interpretations of the tentative NOS concept. At the same time, while Joni and Michelle each had similar definitions of science, they described other aspects of the NOS quite differently. Thus, we see that
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one's conception of one aspect of NOS does not necessarily influence another NOS conception. Rather, each individual conceptual ecology – what the learner brings to the learning environment and how she evaluates knowledge – prominently influences her own interpretation of science's nature. We argue that the actuality of this influence is largely ignored in other work in NOS learning.

*The Moon, the Big Bang, and the atom*

While the previous section of results showed the variety of NOS conceptions that can be had, this section focuses on the surprising similarity of conceptions between learners. What follows in this section is the primary data considered in our discussion. Again, conceptual ecologies are tremendously prominent in how these learners evaluate science and the knowledge it produces. Highlighted are conceptions of NOS that could be applied differently depending on a given situation and the learner's evaluation of such. What we find intriguing (and, thus, what we follow up on in the discussion of this article) is how consistent each of these learners is compared to one another, yet how inconsistent each individual learner is in portraying the nature of science as a result of her conceptual ecology and the extrarational evaluations that come into consideration.

Three specific interview probes are described: One IAI, a questioning about the structure of the atom as it was presented in class, and two CIs, questions about student protests to the Earth being a sphere and about Big Bang theory. 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.

**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?)*

*Micelle:* 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 results to follow show that Michelle is not as comfortable with and confident about the reality of 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, Laura is asked 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 idea she suggests 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 she finds the kind of science knowledge that is represented by science textbooks as 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
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 it was created in a much more deliberate fashion.

Michelle: To this first of two critical incidents, Michelle gives the following measured response:

Hmmm. Um . . . I don't know, I'd probably say [to the student] 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 deemphasize such topics, only to “maybe just sort of go over it quickly” (p. 4).
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_Jamie_: Critical incidents that deal with knowledge are 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_: In response to this probe, 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 she and the researcher 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. As with some other challenging situations, Laura tends to feel uncomfortable in confronting a controversial situation. Both her lack of knowledge of how to portray science and her low self-efficacy inhibit her responses.

_Joni_: “Oh, that is so hard,” (Jo5, p. 5) Joni exclaims in response. “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 acceptable, 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 (Lederman, 1992), 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. In either case, Joni is weighing factors besides her own most commonly stated conception of what a scientific theory is. In response to this 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 to the Moon are part of a government hoax.

Michelle: 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 . . .
Michelle, like the other participants, 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 this issue, 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:
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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. Because 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. 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 with 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
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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

The three probes’ data revealed above mean more as a set than they would as individual data sets. What is revealed is that an individual learner can (and does!) evaluate certain aspects of NOS on a case-by-case
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basis. We argue that the comparison of the responses to these three probes shows two important aspects of NOS concept understanding: That NOS is learned in highly content specific ways (related literature) as well as 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 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 extrarational – 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 they consider "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 extrarational interpretations. Moreover, these learners make no suggestion that they are aware of the fact that they are coming up with such different evaluations. The extrarational 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, 2001). 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, but only in select cases. Extrarational 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 some specific aspects 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. More importantly, even for learners who can at times represent and advocate the way of knowing of science, extrarational factors work to interact with and complicate that understanding.

With many, more traditional science concepts, extrarational evaluation does not become a factor because the concept does not interact with a learner’s affections, beliefs, fears, and the like. For example, research concerning conceptual change and misconceptions of the concepts of heat and temperature (Chi & Slotta,
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1993; Driver, Squires, Rushworth, & Wood-Robinson, 1994) show that, while “heat” is an oft misunderstood construct, the difficulty lies in how we rationally and logically try to make sense of such a construct.

Similarly, research into misconceptions the change of seasons (Driver et al., 1994) shows that the source of misconceptions can result from making very logical conclusions from viable data, such as the fact that the Earth does change its distance from the Sun and that this can rationally lead a learner to construct a misconception.

In our study, we witness the fact that there also exist multiple catalysts for extrarational evaluation. First, we see learners being comfortable in believing in the truth of the atom and its model. This results not necessarily from their understanding of how the model of the atom is created, but possibly the result of the fact that it is such an accepted piece of science understanding – one which was advocated for learning in this class and in other classes. Further, the typical picture of the atom does not challenge or otherwise interact with other firmly entrenched beliefs.

The issue brought to light by the flat Earth CI highlights motivation (Pintrich et al., 1993) as a source of evaluation by the learner. These learners actually pictured themselves as teachers and as being responsible for student learning. Also, we again present a believable concept without viable alternatives (at least for these case study participants). Valuing the importance of this scientific knowledge (both for its own sake as well as for her credibility as a teacher), each participant began to make it clear that, for her, there should be no other way of understanding the situation at hand besides that of science. In the particular case of the flat Earth CI, the learners did not recognize that there could possibly be any other way of knowing. While they were advocating some scientific knowledge that all science educators could agree upon as worthy, they were simultaneously advocating a view of the NOS that was scientistic – meaning that this view does not accept other ways of knowing and their potential sources (Duschl, 1988).

This is sharply contrasted with the Big Bang CI. Here, learners present a view of science's way of
knowing as *not* being valid and as *not* advocating their own personal truths. In these cases, religious beliefs and their resulting extrarational evaluations are evoked. They go one step beyond the acceptance of multiple ways of knowing and actually devalue science and its way of knowing – the same way of knowing which they were confident in when it produced a description of the atom. Also, the definition of "theory" that the participants employed changed as a result. Joni, in particular, was especially adept at describing the shared validity and tentativeness of scientific theories and laws. However, in response to this prompt, she (and others) picked at the use of "theory" in the Big Bang in order to support her own extrarational evaluation. This was done without reflecting upon her description of a theory in other cases or her acceptance of scientific inference in other situations besides the Big Bang CI.

**Implications**

This research's strengths are not in revealing exactly what all learners of the NOS are cognitively taking with them to the classroom. On the contrary, our study reveals that the individual comes to an understanding of science's nature through a very individual path. Our data show rich complexities involved in understanding the NOS resulting from a learner's conceptual ecology. In many cases, this results in a varied understanding of the NOS, as revealed via in-depth qualitative probes. In other cases, multiple learners can reveal similar responses to NOS probes, even if a sequence of probes for a single learner are logically inconsistent. This should have several implications.

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. A learner is making sense of new concepts and of the world about her at the same time. Since this individual is herself responsible for this negotiation, we must realize that explicit attention to NOS concepts may not always be enough. Akerson and colleagues have demonstrated that the learning of NOS concepts benefit from not only their explicit instruction, but by and individual's continual reflection and challenge of her
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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). This might seem obvious to the reader, but it is an issue less taken up in the literature than may be expected.

Similarly, our study has a specific message for research in NOS understandings. These concepts are deeply connected to and interactive with a learner’s values and emotional commitments. Currently, research regarding NOS teaching and learning does little to look at the specifics of such connections and interactions. Granted, understanding the NOS in a purely rational, cognitive way (i.e., without regard to emotional, value laden, or belief enhanced evaluations) should already be a challenge to learners, worthy of its own line of research. However, our research points out that we would be in error if we ignored a learner’s extrarational evaluations, and we cannot presume that a learner’s stated conception of an aspect of the NOS (even as revealed by qualitative probes) will be consistent in all situations. Learners can compartmentalize concepts of the NOS so that they have different meanings in different contexts, just as learners similarly compartmentalize conceptions in other science content (Demastes-Southerland, Good, & Peebles, 1996; Driver, Asoko, Leach, Mortimer, & Scott, 1994).

Our work speaks to other extant assumptions found in the literature. In Abd-El-Khalick & Lederman (2000, p. 1088) it is suggested that:

. . . certain views of NOS have already been imposed on students. It is highly unlikely that students have come to harbor the well-documented and persistent NOS misconceptions merely by internalizing implicit messages about science embedded in their high school and college science experiences. It is more likely that those students were explicitly taught certain naive ideas about NOS.
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While this may be true in many cases (e.g., that theories are tentative but laws are set-in-stone), our research suggests that there do exist conceptions of NOS which are extrarationally constructed by the learner by utilizing only implicit messages in school, society, and culture. However, this is by no means an argument against the literature documenting the effective use of explicit NOS instruction. In fact, we would concur with previous wisdom that explicit NOS instruction is necessary, using the conceptual change argument—also suggested by Abd-El-Khalick & Lederman (2000) and utilized by Akerson & Abd-El-Khalick (2000)—that learners must be made aware of their own conceptions in order to become dissatisfied with these and change them.

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. The extent to which students apply these kinds of spontaneous constructions could be a fruitful research pursuit.

Our research leaves open many other research questions and pursuits. First, it definitely supports the call for a greater use of qualitative probes in order to understand learners' NOS conceptions (Lederman et al., 1998). The use of such probing will allow other questions to be asked. For example, how can a learner become aware of and distinguish rational from extrarational thinking? While we do not wish to eradicate extrarational thinking, we argue that learners' will not only understand science better if they understand how to distinguish different epistemologies, but that they will understand their own thinking. This promises some fruitful research.

Conclusion
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The analogy that NOS cannot be learned through implicit instruction just as respiration cannot be learned via the act of breathing is well founded (Abd-El-Khalick et al., 1998). However, this falls short in one respect: Breathing and respiration are non-confrontational to our beliefs, values, emotions, etc. NOS concepts do, fundamentally, interact with our extrarational evaluations much more than breathing, respiration, and other concepts. We, both teachers and researchers (as well as learners) would do well to recognize the many possible ways that a single concept could be evaluated by a learner, whether we would agree with such possibilities or not.

Our research shows how extrarational evaluations can dominate the conceptual ecology, overruling other evaluations that may be more empirically based. While a specific NOS conception is used in some cases (such as the idea that explanations in science can be inferred indirectly rather than observed directly), the conceptions are 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
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find certain actions reasonable, though he or she may not be able to explicitly describe the reasons. We argue that the extrarational evaluations exhibited by our case study participants suggest the nature of understanding NOS ideas is even more complicated than previously demonstrated. 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 – not only her rationalized conceptions, but also her extrarational evaluations.
### Table 1:
Summary of case study comparisons

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</tr>
<tr>
<td><strong>Jamie:</strong></td>
<td>a process used towards producing knowledge</td>
<td>for explanation</td>
<td>segregation</td>
<td>tentative due to mistakes</td>
</tr>
<tr>
<td><strong>Laura:</strong></td>
<td>is knowledge and nature/world</td>
<td>vague</td>
<td>vague</td>
<td>non-tentative</td>
</tr>
<tr>
<td><strong>Joni:</strong></td>
<td>a process (limited), with emphasis on products</td>
<td>for utility (personal and health)</td>
<td>integration</td>
<td>tentative (as evidenced by personal beliefs)</td>
</tr>
</tbody>
</table>
References


Extrarational Evaluations of the Nature of Science

Science Teaching, New Orleans, LA.


Extrarational Evaluations of the Nature of Science


