Conceptual ecologies and their influence on nature of science conceptions: More dazed and confused than ever

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ABSTRACT: This research analyzed teachers conceptions of the nature of science and how they developed during a graduate course which was focused on the nature of science and how it is learned. These teachers engaged with nature of science concepts explicitly and reflectively, considering the concepts in the contexts of science itself as well as in their respective classrooms. Through a series of questionnaires, reflection papers, classroom activities, and a final paper, each teacher's development of his or her conceptions regarding the nature of science was recorded. By analyzing this data, we show how each individual conceptual ecology strongly interacted with concepts from the course to produce understandings unique to an individual. This has implications for both our design of nature of science instruction and for our understanding of the conceptual change process and learning in general.

Introduction

This paper was supposed to be the presentation of an ideal teaching situation with an ideal group of learners in a classroom with the most informed curricular and pedagogical choices. As a result, this paper was supposed to show that everything we – science education researchers who are particularly concerned with how learners come to understand the *nature of science* (NOS) – are currently concluding about NOS teaching is correct and is likewise progressively moving our society towards a greater literacy in science. Unfortunately, we learned that our learners are *human*, and as such, they each maintained their individualities and the pieces that sum to such individualities. These pieces included different approaches to science, different attitudes towards, views of, and strategies for learning, and differing conceptions of knowledge itself. What was set up to succeed was destined to fail because we, unfortunately, decided to conduct research on human learners rather than on pigeons.

Although we open this paper a bit flippantly, the point remains: Learning about the NOS is difficult. However, this research was based on the idea the learners can learn about the NOS if the topic is treated in a specific manner. The NOS must be taught in an explicit manner, giving students the opportunity to reflect upon their own conceptualizations of NOS, and giving students a context of science content to attach NOS concepts to. NOS concepts are not themselves clear to the learner if they are not treated as distinct, to-be-learned ideas. It might seem that learning science content in an inquiry based setting would make NOS obvious, but it does not; and it would seem that teaching about the development of knowledge through the history of science would make the NOS clear, but this simply is not true. Teaching science, we learn time after time, is challenging. So, too, is learning it. We should have known better.

We – the authors of this paper – thought that we knew better. We read your research papers; we listened to the presentations in conferences; we observed our own students. What we found, however, is that our students continue to surprise us with how comfortable they can be with preexisting ideas; and they surprise with how willing they can be (in some instances) to tackle new ideas. Most surprising was finding which learners fit into which of these groups: Those whose conceptions are cemented into a rigid framework of ideas, and those who are able or willing or anxious to rearrange a framework to fit knew ideas into new contexts.

Background

First, we should clarify what it is that we, as researchers, already know about teaching and learning the nature of science. Historically, NOS has been nebulous, abstract, and often simply left unaddressed in science classrooms. It is easy (relatively speaking) to teach and learn the "answers" of science, but leave out the questions, where the questions come from, what kinds of questions can be asked, how we try to answer the questions, and what assumptions we make about the nature of the universe and what we can know about it. Looking at this list, it looks as though we are leaving out a great deal of what we call "science" – specifically what we call the nature of science.

As the first author will personally attest[1], it is easy for a science instructor to assume that students will simply "get" the NOS as it bubbles up out of the background of typical science instruction. We assume that while students are doing an experiment they will come to understand something about the empirical nature of science. We might assume that if we show the historical development of science, learners will understand how science knowledge is tentative, yet durable. We probably too often assume that since our science classes only provide answers to certain questions that our students will learn that science can only ask and answer certain types of questions. We assume wrong.

Research shows very clearly that NOS concepts must be taught deliberately and planned into a curriculum as a central theme. Specifically, we highlight three features of NOS instruction that have been shown to amplify the learning of NOS concepts:

NOS instruction must be explicit. Many have done work to show that NOS concepts are more readily understood by learners when such concepts are taught in an explicit manner (Abd-El-Khalick, Bell, & Lederman, 1998; Gess-Newsome, 2002; Lederman, 1999; Southerland & Gess-Newsome, 1999). This is not to say that the NOS must be taught in a didactic manner in which a learner is forced to memorize key concepts and parrot them back on a multiple choice exam. Rather, "explicit" means that the NOS concepts we hope for our students to learn must be identified clearly to students so that they know what it is they are supposed to be understanding in the first place. If a learner is not aware that a concept even exists, she will not learn it. Instead, she will assume that what a science teacher might think of as NOS is really just common sense – but "common sense" does not necessarily explain the NOS (Johnston, 2001).

NOS concepts are best understood in the context of science content. Many concepts of the NOS might have some logical coherence to them on their own, but they really do not mean anything if they are not applied to science content itself. This has been suggested by others and curricular reforms and suggestions have been made as a result (Clough & Olsen, 2001; Smith & Scharmann, 1999). Much of the difficulty in understanding the NOS lies both in the fact that NOS ideas are especially abstract and removed from everyday experiences, and in the fact that our awareness of NOS concepts tends to be very low. Thus, the challenge of trying to teach the NOS is not only inherent in the complexities of the subject matter itself, but because we must expose to our students/teachers that these concepts are important to their understanding of science in general. This can only make sense when NOS is given a context within the science content that we are more familiar with teaching and learning.

NOS learning should be reflective. More success seems to be apparent when a curriculum is designed in such a way as to force the learner to reflect upon his own conception of some aspect of the NOS, and then actively compare this to another, competing (and more informed) conception of the NOS (Akerson, Abd-El-Khalick, & Lederman, 2000; Akerson & Abd-El-Khalick, 2000; Loving & Foster, 2000). Such a process further engages the

[1] I had once idealized that NOS ideas could be naturally absorbed by learners in the context of an extraordinary science classroom. I learned otherwise long before undertaking this project (Johnston, 2001).

student, makes him aware of his own preexisting conceptions, and forces him to more deeply consider the possible conceptions.

This latter strategy is informed by conceptual change theory, which suggests that much of our learning is accounted for by a conceptual change process. As originally proposed (Posner, Strike, Hewson, & Gertzog, 1982), conceptual change theory suggests that the most revolutionary kinds of learning take place when a learner's preexisting conception must be completely thrown out and replaced by a new concept due to the fact that the new and old concepts are not logically compatible. This can only take place when the learner finds dissatisfaction with the old concept, finds the new one understandable, plausible, and fruitful in new and existing contexts. Undoubtedly, this could explain why many ideas are so difficult to learn – they face a number of obstacles.

However, it may not even be this simple for conceptual change to take place. Many have suggested and demonstrated how one's conceptual ecology – a learner's existing knowledge, attitudes, emotions, predispositions, etc., and how these interact – impact the conceptual change process (Demastes-Southerland, Good, & Peebles, 1995; Johnston, 2001; Strike & Posner, 1992). Therefore, conceptual change is not as logical and easy to direct as we (as teachers and designers of curricula) may desire. Concepts which interact with a learner's emotions are especially susceptible; and the NOS shows great potential for such interaction (Johnston & Southerland, 2001; Smith & Scharmann, 1999).

Our research looks at the conceptual ecologies of learners and how they interact with the learning of the NOS. The goal of this would be to not only inform research and curriculum regarding the NOS, but to also further the research regarding conceptual change theory and the interaction of the conceptual ecology with learning in general.

Setting and methodology

This study was essentially initiated when the second author asked the first author to teach a graduate course in science education called, "The nature of science and science education." The first author, being fresh out of graduate school, hopelessly naive (especially in regards to the pitiful salaries that adjunct instructors receive), and eager to expand upon his vita, enthusiastically agreed. Having taught a wide variety of physics courses to undergraduates, this course provided a refreshing change of curriculum and pedagogy, and provided the venue through which he could continue to discuss ideas that were relevant to his research. In addition, the course would provide a fresh opportunity to engage students in NOS learning as advocated by the research described above.

Enrolled in the class were 11 students, each of which was either a practicing teacher or a teacher on a sabbatical leave from a teaching position. These students were, as a group, experienced with a wide range of grade levels (K-12) and classes (e.g., general elementary classes, bilingual classrooms, middle school science, and high school biology). As suggested by the course's title, the curriculum focused on what the NOS is, what aspects of it are important in specific classrooms and towards science literacy in general, and how such aspects should be taught in specific classrooms.

Following the recommendations and previous successes of other NOS instructional efforts, this class utilized a series of readings, reflections, written responses, and discussions to enhance learners' awareness of NOS concepts. In addition, class sessions generally included mini science lessons (e.g., an activity using soap bubbles and their observation, an effort to understand a mechanism of the changing pitch of stirred hot chocolate, a session in which groups tried to build a model of the solar system based on observations, etc.) and explicit debriefing and discussion sessions to describe the NOS inherent in actually "doing" science both in the classroom and in the laboratory. When the science examples were not included in a class session, other explicit NOS activities were done. These included card sorts of NOS terms (Gess-Newsome, 2002; Johnston & Southerland, 2001), discussion of whether or not certain questions and issues were "scientific" (Smith & Scharmann, 1999), and the use of critical incidents (Johnston & Southerland, 2001; Nott & Wellington, 1998) – hypothetical situations that could take place in the classroom and the evaluation of how a teacher should react to such, and why.

Data collected included field notes of all class sessions[2]; the instructor's class notes, written reflections, and written comments on student papers; student responses to selected questions from the VNOS questionnaire (Lederman et al., 2001) both at the introduction and end of the course; students' response papers (described below); and students' final papers.

[2]Special thanks and acknowledgment to Julie Kittleson for collecting and organizing this data.

The response papers were meant to be a means of eliciting student conceptions after having done specific readings but before class discussion on a particular NOS topic had taken place. Response paper questions included the following:

- What is the difference between a scientific "fact," "law," and "theory"? How do these interact with one another? Why is it important to understand this, and how does/should this be represented in the classroom?
- What does it mean for science to be "tentative" or "changeable"? What examples can you describe for this? Why is this important for students to know; and how can this be portrayed in the classroom?
- Is scientific knowledge created or is it discovered? What is the difference? How does/should this aspect of science be represented in a science classroom? Why is this issue important to science education?
- Talk back to Mahner and Bunge (1996). What points are they trying to make, and to what extent do you agree or disagree with them? Why?[3]
- Compare science and religion. Specifically, how does science come to understand the world, and how does religion come to understand the world -- are these views compatible? Why is this important for science education? How should this be portrayed in the classroom?

[3]The idea for this particular reading and response is taken directly from Loving and Foster (2000).

The final paper was meant to be a synthesis of all that each student had learned in the class, and most importantly, a way for each student to describe how and why they would implement NOS curricula into her own classroom. Specifically, the following points were asked for:

1. What, in your view, is the nature of science? How has your conception changed?
2. What aspects of the nature of science should a "scientifically literate" citizen know? Why?
3. What aspects of the nature of science should be emphasized in *your* classroom? Why?
4. How can the nature of science be most effectively taught in your classroom? Justify your ideas.

From the data provided for each learner, a set of NOS concepts was evaluated, including the definition and purpose of science, the source of scientific knowledge, the tentative nature of scientific knowledge, the definition of a scientific theory and its comparison to a scientific law, the role of background knowledge and culture in science, the role of imagination and creativity in science, and the distinction between science and religion. All data were analyzed using constant comparative analysis (Strauss & Corbin, 1998) for each individual learner's data set. More specifically, the first author analyzed the NOS understandings of each student and documented these throughout the duration of the course. Then, copies of all data were given to the second author for her analysis. The interpretations of each author were then compared. In rare instances where disagreement arose between interpretations, the team reevaluated the data and a given interpretation together, resolving such differences.

Results

We have a rich array of qualitative data from which to base our findings. Making sense of this data becomes a challenging problem. At this point in our research, we are still attempting to make sense of these data and to determine a more effective way to organize them. This conference paper is, in our view, a first step. More data, more thought, and interaction with colleagues should help us to develop our ideas more clearly. In what follows, we present our synthesis of all the data, but we remind the reader that these data include student responses to VNOS questions, reflection papers, final papers, and class interactions.

Table 1 shows a matrix of how we have evaluated (in terms of "low," "moderate," or "high") the NOS conceptions of our graduate student learners. This includes our assessments of each learner's NOS understandings before and after instruction, leading to an assessment of the degree of change in their NOS understandings. Alongside these data are descriptors regarding other knowledge and background that each learner brought to the classroom: science content knowledge, confidence in their NOS ideas, motivation to learn NOS, reflection and intentionality in learning, and self-efficacy towards learning.

As shown in the table, learners' development of NOS ideas was widely varied and largely independent of one's scientific background. A learner such as Carla, who was especially familiar with and active in developing state curriculum standards for the

NOS, could should very little development in her NOS conceptions. This was in spite of the fact that her initial conceptions were much less informed than would be expected for someone with a great deal of experience teaching high school biology and developing curricular standards for the state. At the end of the study in her final paper, Carla was still describing theories as being speculative and laws as being immutable pieces of knowledge. Considering she was a learner with a rich, scientific conceptual framework upon which to develop her NOS understandings, this was depressing (especially from the perspective of the instructor who graded the paper).

At the same time, Ellen came to this classroom with very little ideas as to what the class was even supposed to be about – and she was not alone in this respect. Ellen, as a third grade teacher, was enrolling in the course in order to earn some graduate credit and potentially help her begin to develop some science curriculum. The "nature of science" had virtually no meaning to her at the beginning of the course, since she had no background knowledge in the field, nor did she have much in the way of formal science coursework in her previous classroom experiences. However, once Ellen began to understand what the NOS is, she began to embrace it as an important part of what her classroom should focus upon. Often she came to class to report experiences with her third graders and how she had experimented with new activities and discussions to introduce NOS concepts to young students. For example, after having observed soap bubbles in her graduate class, Ellen had her own students engage in the same activity later that week. Returning to class full of graduate students, Ellen described what she had done and probed her classmates and instructor for ideas about what to do next. Although her anxiety about not knowing enough science content was apparent, she was also willing to play with the new ideas and apply them to her own situation. As a result, Ellen's development of NOS concepts was striking.

Comparing Carla to Ellen shows us that, at least in this case, the previous experience that one has with NOS and science knowledge is not necessarily a predictor of conceptual development of NOS ideas. In fact, this example suggests that Carla's confidence in her science knowledge, her NOS knowledge, and her science teaching actually could have inhibited her learning more about the NOS. In stark contrast, Ellen only knew that she knew nothing about NOS. Her deep reflection and deliberate consideration of her own conceptual framework allowed her to make great strides in her NOS understanding. In fact, not only was her change in conceptions much greater than Carla's, but she actually ended the course with a much more informed and elaborate description of the NOS.

Diane is a middle school science teacher on a sabbatical in order to take more coursework and reflect on her teaching. With many years of teaching experience and with a well developed understanding of the middle school science that she taught, she was already content with much about her teaching and her curriculum. However, at the outset of the course she had very little conceptual framework developed for NOS. Like Ellen, though, she seemed to show a natural tendency for reflecting on new ideas and trying to developing her own understandings in an intentional manner. This might be contrasted to Norm, also an experienced middle school science teacher, and with science research experience and a graduate degree in geoscience. Norm was confident in his ideas and in his teaching. He, along with Carla and Devin, was often one who would offer advice to others in the class about teaching science content and the NOS. Yet, he himself did not have especially well developed conceptions of NOS. Although he is well spoken, his conceptions are not well elaborated and generally left very vague. Norm, in general, seemed to write statements in reflection papers that would appease the instructor on some level, but not necessarily engage the concepts at hand.

Despite some comparisons that can be made between seemingly “opposite” learners, there are no clear indicators of NOS learning success. Devin, with a strong background in science teaching, did quickly show a strong understanding of NOS compared to others with similar backgrounds. Devin’s understandings, however, were probably not as sophisticated as Kate’s. Kate had little background in science (although a strong background as a graduate student in education) and taught the third grade. In spite of this – or perhaps because of it – she was often the member of the class who could bring clarity to a discussion and even speak to counter and correct the statements of the more experienced science teachers in the class. Similarly, Tina and Noelle each teach lower grades and both showed active engagement with the material – Tina especially so in class discussions and Noelle more so in her written work. Yet, in spite of the seeming parallel, Noelle’s understanding of NOS and its application to a classroom setting was far more advanced than Tina’s.

Thus, our results could be summed up as being mixed; more mixed than we ever would have imagined, in fact. Perhaps we should have seen this coming, for we filled a classroom with a group of diverse learners, with diverse backgrounds, and with diverse teaching assignments. If only we had studied pigeons . . .

Discussion

The nature of science is not an isolated, straightforward concept. It is abstract and large, composed of many sub-concepts which interrelate and entwine. Most of us take for granted that a NOS should even exist, just as we often take for granted that science should exist. So, since NOS is an abstract, intricately complicated, and often unacknowledged concept, it is no wonder that our learners have a difficult time understanding it.

At the same time, we have developed a good idea as to what *should* work to help learners understand NOS. To a great extent, this course modeled the kind of NOS instruction and interactions that are supposed to enhance NOS learning. Granted, other studies have suggested the use of not just one class, but entire programs emphasizing the explicit teaching of NOS (e.g., Olsen & Clough, 2001) as well as its integration into student teaching programs (e.g., Lederman, 1999; Schwartz & Lederman, 2002). This was only a one semester course, so we may very well expect smaller gains. On the other hand, we see results that are so mixed that we start to question one of our initial assumptions – an assumption we probably were not even aware that we had at the outset. That is, we assume that all of our students will respond in similar ways to the same instruction, curriculum, activities, readings, etc., so long as they have similar backgrounds. In this research we have witnessed how seemingly diverse learners can come to the same informed (or misinformed) understandings of NOS, while at the same time two very similar individuals come to completely different conclusions about NOS. What are we to make of this?

We tend to blame the conceptual ecology (Strike & Posner, 1990) of each learner – the vagary background knowledge, beliefs, attitudes, and previous experiences that shape how a learner interprets and uses new (as well as existing) information. Specifically, we look to each learner's science background and each learner's reflectivity and intentionality in learning as key elements that may be determining the extent to which their NOS concepts develop.

Learning something from previous research, we first considered that this classroom was composed of both "wonderers" and "knowers" (Smith & Anderson, 1999). Wonderers are characterized as those who have had little science experience, and what they may have had may have been alienating rather than fulfilling for these learners. In contrast, knowers have a wealth of background knowledge in science, and are quick to refer to such knowledge as a basis for explanation. What Smith and Anderson demonstrated is that those who know are often impeded by their own confidence in their knowing, and those who wonder are often served well by their desire to question. To a great extent, Norm and Carla seemed to be examples of "knowers" who could not get beyond the comfort they had with their own perceived expertise. Kate and Ellen – clear "wonderers" in regards to backgrounds in science – were seemingly much more open to new ideas, since they had no other ideas to defend. They clearly identified a gap in their understanding and tried to fill it, while Norm and Carla took information from the course to assimilate onto a rigid conceptual framework that they had already constructed for themselves and apparently felt quite comfortable with.

Those examples and the examples of Smith and Anderson are in contrast to other recent work. Specifically, Schwartz and Lederman (2002) showed individuals whose science content knowledge helped in their conceptualization of the NOS. To us, this makes perfect sense: Understanding more science content knowledge should provide a solid conceptual foundation and a rich selection of background knowledge to help solidify the understanding of the NOS. And, a learner in our study, Diane, seemed to support this notion. However, we found evidence to the contrary of any general correlation between content knowledge and NOS understanding. In fact, had we selected only a few participants out of this class, we may very well have suggested an inverse relation between science content knowledge and NOS understanding. Several things may be taking place. Perhaps the way in which content knowledge itself is understood could in some way determine how NOS is understood. More likely to us, however, would be the proposal that an overriding factor determines NOS understanding. In our participants, individual reflection seemed to be a better indicator of gains in NOS understanding than any background knowledge.

Still, there is more to learning than knowing and wondering. There is also reflecting, feeling, thinking, working, striving, wrestling, rationalizing, and other -ings. Learning is a doing process. It is active, and it is engaged with the learner in at least three specific ways. First, we know that learning must take place in the context of what a learner already "knows" – that is, what the learner has already collected and integrated into a framework of workable knowledge. This knowledge should somehow be self-consistent and supportive of one another (Vosniadou, 1994). Second, learning takes place often in the context of a conceptual ecology (Demastes-Southerland et al., 1995; Johnston & Southerland, 2001; Strike & Posner, 1990) . Even when we have the correct pieces and can see how they fit together, we do not always finish the assembly process. This might be simply because we do not want to – maybe it takes too much effort – or because it conflicts with some other fundamental assumption about how the world *should* be. This takes place in instances from denying that objects fall at the same rate even when they had been observed to do so (Hynd, 1998) to revising our ideas of how science operates based on our spiritual views (Johnston & Southerland, 2001).

Schwartz and Lederman (2002) also conclude that it may be the case that teachers who learn and teach NOS early in their careers – specifically as student teachers – may be better enabled to understand and explicitly teach NOS in their classrooms. Certainly, our experienced science teachers may also back such a suggestion, but our learners who have already been teaching in the classroom for some years without even realizing the existence of NOS concepts seem to be making major strides towards incorporating NOS in the contexts of their specific classrooms. Although time will tell how well these NOS concepts actually get incorporated into their classrooms, we suggest that they may be more enabled to teach NOS in the long run due to an overall willingness to *begin* to teach science in their classrooms. Other, established science teachers may have been especially resistant to *learning* NOS because they could not conceive of *teaching* any differently.

Finally – and perhaps especially important – learning itself must be conceptualized in order for certain learning to take place. For example, a learner who equates learning with memorization will not really understand Newtonian mechanics, and an individual who thinks she already understands the NOS will incorporate new NOS ideas into an existing framework, not necessarily learning any new NOS concepts. The kind of learning that takes place is determined by how intentional the learner is in this process (Sinatra & Pintrich, in press; Southerland & Sinatra, in press). Of course, how a learner conceptualizes learning itself may very well depend on the content to be learned and his view of this content. If a learner, such as Carla, see NOS ideas as those which can be incorporated and added simply to an already existent conceptual framework, then the understanding of these NOS ideas may be predetermined to be very shallow. On the other hand, a learner such as Ellen, who views the learning process for NOS as being more difficult to begin with (due to her lack of experience with the subject), will be more deliberate in her learning. Granted, much of the learning that we do is probably unintentional and is composed of assimilated information into a preexisting conceptual framework (Vosniadou, 2002), but this kind of learning is short of what is required to really understand concepts such as biological evolution, special relativity, or the NOS.

Confusion

Overall, while many different attitudes towards science and science teaching were portrayed, these learners' final conceptions of the NOS were much more articulate and sophisticated than they were at the outset of the course. This supports much of the previous work done regarding the design of NOS curricula and how learning the NOS is facilitated by explicit instruction, reflective activities, and context specific examples.

However, we also witnessed the very sophisticated interaction between learners' conceptual ecologies and their conceptions of the NOS. As we have stated from the outset of this paper, this research was supposed to be very straightforward. Essentially we sought to integrate what research has already told us is supposed to help NOS learning to take place, and then report on how well this all worked out. Although several learners did take away a great deal from the course and its explicit reflective treatment of NOS concepts, we were still dismayed by much of our results. After all, these students are advanced thinkers, capable of processing heavy loads of information, even when such is abstract. The issue then becomes not one of what our students are capable of, but of what they already know, how they view the nature of the knowledge that they are learning, and how they view the learning process of that knowledge. The nature of science seems to be especially vulnerable to these issues, and we are left to wonder how to make greater sense of them and their interplay with NOS learning.

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Table 1:

Evaluations of NOS understandings and conceptual ecologies

(Note: Learners are listed in order of the grade level they teach, from highest to lowest.)

	NOS (pre)	NOS (post)	NOS change	Science content knowledge	NOS confidence	NOS motivation	Reflection / intention	Self-efficacy for learning	Teaching
Devin	High	High	Low	High	High	High	Moderate	High	H.S. science
Carla	Moderate	Moderate	Low	High	High	High	Low	High	H.S. science
Norm	Low	Low	Low	High	High	Moderate	Low	High	M.S. science
Diane	Low	High	High	High	High	Moderate	High	High	M.S. science
Nancy	Low	Low	Low	Moderate	Moderate	Moderate	Moderate	Moderate	6th grade
Tina	Low	Moderate	Moderate	Low	Low	Moderate	High	Moderate	3rd grade
Mary	Low	Low	Low	Low	Low	Low	Low	Low	3rd grade
Ellen	Low	High	High	Low	Low	Moderate	High	High	3rd grade
Kate	Low	High	High	Low	Moderate	Moderate	High	High	3rd grade
Noelle	Low	High	High	Low	Moderate	Moderate	High	Moderate	1st grade
Sharon	Low	Moderate	Moderate	Low	Moderate	Low	Moderate	Moderate	Preschool