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Continuum: Selecting Inquiry-Based Experiences to Promote a Deeper Understanding of the Nature of Science

Matthew D. Bannerman
Clarke High School, Osceola

CONTINUUM

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SELECTING INQUIRY-BASED EXPERIENCES TO PROMOTE A DEEPER UNDERSTANDING OF THE NATURE OF SCIENCE

Matthew D. Bannerman
Clark High School, Osceola

ABSTRACT: Whether explicitly or implicitly, science teachers constantly convey an image of the nature of science (NOS) in their classrooms. The actions of the teacher, how the class is run, and the instructional patterns all convey an image of what authentic science is like. As such, significant attention to inquiry-based instructional practices is required to accurately portray the NOS. However, even teaching through inquiry, while necessary, is insufficient for NOS understanding. This article presents four factors that teachers should consider when teaching the NOS. *This article addresses National Science Education Content Standards A and G, and Iowa Teaching Standards 3,4, and 5.*

"The ability to distinguish good science from parodies and pseudoscience depends on a grasp of the nature of science." (Matthews, 1998)

Compelling arguments for accurately teaching about the nature of science (NOS) have been repeatedly made in the science education literature (AAAS, 1989; Matthews, 1994; McComas, Clough, & Almazroa, 1998). Many teachers do not recognize that they are conveying messages about science itself and how science works, whether or not they intend to. The manner that science content is taught conveys messages about what science is and how it works. Just as important, accurate NOS understanding often promotes science content understanding (McComas et al, 1998). The importance of accurately conveying the NOS in a science classroom, then, cannot be overstated; scientific literacy depends heavily on it.

While much literature addresses how to effectively teach the NOS, science teachers have to determine how best to implement such instruction into their classroom. The many institutional constraints they face are real and may tempt teachers to simply convey accurate NOS ideas to their students via the time-honored lecture and reading approach. While requiring less preparation and instructional time, these methods do little to create the concrete experiences and mentally engaging learning environment students need to develop a thorough and robust understanding of the NOS (Clough, 2007; McComas et al, 1998).

Effectively incorporating accurate NOS instruction does not mean adding another topic or unit to an already overstuffed curriculum. Rather, the science concepts we already teach must be conveyed to students in a manner that also accurately conveys what authentic science is like. Doing so can be challenging; for instance, how do we manage a class of students in an inquiry-based activity if no single step-by-step scientific method exists? How should laboratory reports be graded if making errors is part of doing science? Teaching science through inquiry and accurately conveying the NOS does not mean that anything goes or that understanding presently accepted scientific knowledge is down played. However, it does at times require reconsideration of how science content is taught.

Considerations for Effective Teaching the NOS

Any serious consideration of the NOS is inherently abstract; the teacher is asking students to think about their thinking regarding science and its processes and compare that to how science really works something they have not directly experienced. What makes this all the more difficult is that how science actually works is often at odds with how we teach science. Accurately and effectively teaching the NOS requires attention to four key features that exist on a continuum:

1. concrete experiences to abstract ideas,
2. activities that range from cookbook procedures to open inquiry,
3. activities and experiences that range in how closely they are linked to authentic science, and
4. implicit to explicit instruction.

Continuum 1: Concrete to Abstract Science Instruction

Learners have prior knowledge that they use to evaluate the accuracy of incoming information. The challenge for teachers is encouraging students to think about their currently held views and have them wrestle in comparing that to what they are experiencing in our science classes (Watson and Konicek, 1990). Effective science instruction typically scaffolds from concrete experiences to more abstract thinking (Saunders, 1992; Von Glaserfeld, 1989). Concrete experiences are useful to learners because they can draw and build upon those when thinking and building or modifying ideas.

Olson (2008) describes how the methods used to teach science content vary along a continuum from concrete to abstract (Figure 1). Remaining solely at either end of the spectrum is not productive. The key is to begin with concrete experiences and scaffold back and forth between concrete experiences and abstractions. When teaching the NOS, for example, I consider how to use discussion, interactive presentation of information, and readings so that they relate and draw from more concrete NOS experiences I have had my students take part in. And when my students take part in more concrete experiences, I have them relate those experiences to NOS ideas raised in previous discussions, interative presentations of information, and readings.

Continuum 2: Cookbook to Inquiry Science Instruction

Teaching science through inquiry is crucial for providing students a sense of what authentic science is like and for learning science content (NRC, 1996; AAAS, 1989; Dass, Kilby, and Chapell, 2005). However, like the concrete to abstract continuum, this continuum (Figure 2) consists of a progression of activities that range from directive cookbook activities to truly investigatory activities. As Clark, Clough, and Berg (2000) state,

> *In rethinking laboratory activities, too often a false dichotomy is presented to teachers that students must either passively follow a cookbook laboratory procedure or, at the other extreme, investigate a question of their own choosing. These extremes miss the large and fertile middle ground that is typically more pedagogically sound than either end of the continuum.*

FIGURE 1

Activities and tools in a science classroom exist along a continuum from concrete to abstract. Teachers must choose an activity appropriate to their purpose that will also develop student understanding, using their understanding of learning theories and how people learn. (Modified from Olson 2008)

Concrete ... **Abstract**

real objects — video — photos — drawings — graphs — tables — formulas — text — diagrams

FIGURE 2

Activities in a science classroom exist somewhere between being truly cookbook and being truly inquiry. Depending on what instructions are given, what sorts of expected results are present, and how much teacher support students have, even more cookbook activities can prove highly effective.

Cookbook ——— **Inquiry**

These authors point out that students, for safety or cognitive reasons, do sometimes do have to be told precisely what to do. However, rather than mindlessly following directions, students should be engaged in reflecting on the rationale for each step in a directive activity. Moreover, when activities fall short of accurately reflecting the NOS, significant value exists in asking questions such as:

- What about the activity we just did does not accurately reflect how science really works?

Continuum 3: Decontextualized to Contextualized NOS Instruction

A variety of activities may be used to help students come to understand the NOS. These range from what Clough (2006) refers to as decontextualized NOS activities (e.g. 'black box' activities, puzzle solving activities, and pictorial gestalt switches), moderately contextualized activities (e.g. science content inquiry activities), and highly contextualized NOS activities (e.g. links to the work of authentic science and scientists).

At the left side of the continuum (Figure 3), decontextualized NOS activities permit both students and teachers to concentrate solely on NOS issues. This is the case because decontextualized NOS activities are not bound up in science content or the authentic workings of scientists. As instruction moves along the continuum, NOS activities become more embedded in science content being taught. This is important so that students experience some of what doing authentic science is like. However, students might still dismiss these experiences as being “school science”, not what real science is like. That is why highly contextualized NOS instruction is required. Clough (2006) argues that effective NOS instruction scaffolds back and forth along the decontextualized to highly contextualized continuum. Moreover, when implemented effectively, content is learned more deeply because of NOS understanding, and student NOS understanding is at least partly a result of the content in which it is framed (Driver, Leach, Miller, and Scott, 1996).

Continuum 4: Implicit to Explicit NOS Instruction

The view that students will question their NOS misconceptions simply by having experienced inquiry activities seems to make sense. While many NOS issues are implicit in school science inquiry experiences, students often miss them. Clough (2006) explains this in the following manner:

Due to years of school science instruction and everyday out-of-school experiences that have consistently conveyed, both explicitly and implicitly, inaccurate and simplistic portrayals of the NOS, students carry deeply held misconceptions that rarely respond to implicit instruction that faithfully reflects the NOS. The expansive, yet inaccurate frameworks students possess regarding the characteristics of science and how it works act as filters that obscure the more faithful implicit NOS messages in authentic inquiry experiences.

Explicit NOS instruction does not mean lecturing to students about what science is and how it works. Between the two extremes (Figure 4), teachers can do a number of things to bring students' attention to NOS ideas. These entail asking questions that draw students' attention to key NOS ideas. For example:

- How is the way you conducted this inquiry activity similar to and different from how authentic science works?
- How did this directive lab experience distort how authentic science works?
- What does this scientist's account of her research imply how science works?
- The scientists on the video we have just watched stated that doing science is like composing music. In what way is science akin to composing music? How is it different than composing music?

The other authors in this special issue provide many other examples illustrating how to draw students attention to the NOS that fits between the two extremes on this continuum.

FIGURE 3

Because of the abstract nature of NOS ideas, it is often necessary to present them in a manner that is outside the context of science content; however, decontextualized activities are only moderately effective at challenging student ideas. Teachers need to move along the continuum toward more contextualized activities in order to challenge student misconceptions.

Decontextualized ———————————————— **Contextualized**

FIGURE 4

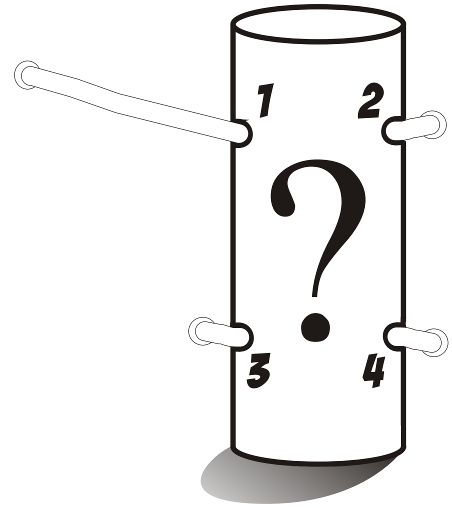
Students will not generally develop accurate NOS conceptions from the implicit messages in even the best activities – it is the responsibility of the teacher to explicitly draw their attention to the ideas and help them challenge their misconceptions..

Implicit ———————————————— **Explicit**

The Sliding Scale: A Framework for Classroom Integration

The four continuums described above are each important on their own, but their value grows when they are considered together. As I make choices regarding how to teach a particular lesson, I mentally consider how my decisions fall on the four continuums. For example, black box activities like that presented in Figure 5 are often used by teachers to teach about the NOS. This decontextuzlized activity is quite concrete and useful for first engaging students in important NOS ideas. However, the many implicit NOS ideas need to be made more explicit. Thus, I have to consider questions that I might ask to draw students' attention to key NOS ideas. The activity has the potential to be quite inquiry oriented, but that depends on how I interact with students. For instance, when they ask me whether the tubes are all the same, I respond that I do not know and urge them to consider how they will answer that question. When students ask me to interpret their data, I instead tell them they are the scientists and must do the interpreting. I might even make the point that scientists have no all knowing person to whom they can go and get their questions answered they must interpret the meaning of data. Keeping the four continuums in mind helps me plan more effective NOS lessons, and make changes in what I intend to do to position each continuum where optimal learning is promoted.

FIGURE 5
The Mystery Tube as an example of a black box activity.
For a full write-up of this activity, see
http://www.bsu.edu/fseec/pie/Lessons/General_Science/Mystery_Tube.doc



Graphic by Joe Taylor

Another example is an activity about the demotion of Pluto to the rank of 'dwarf planet' (Figure 6). I categorized this as a moderately decontextualized NOS activity because it

FIGURE 6
Pluto Activity Worksheet
Adapted from (2006) "Pluto is no longer a planet." [On-Line]. Teachable Moments 1, pp. 1-4. Accessed 09/04/08 from:
http://www.walch.com/teachable/teachable_moments_1_pluto.pdf

Introduction
The first identification of Pluto was spearheaded by Percival Lowell, who founded the Lowell Observatory in Flagstaff, Arizona. He provided financial support for three separate searches for "Planet X." Lowell made numerous unsuccessful calculations to find "Planet X," believing it could be detected from the effect it would have on Neptune's orbit. Dr. Vesto Slipher, the observatory director, hired Clyde Tombaugh for the third search. Clyde took a series of photographs of the plane of the solar system (ecliptic) one to two weeks apart and looked for anything that shifted against the backdrop of stars. His systematic approach was successful and the first observable evidence was seen by a young 24-yearold Kansas lab assistant on February 18, 1930. As it turned out, Pluto is too small to be the "Planet X" Percival Lowell had hoped to find. The first observation of Pluto was a fortunate event.

Directions: Read at least one (preferably two) of the available articles and answer the questions below on a separate sheet of paper. Write your answers in complete sentences and be thorough consider the assumptions of science that have come up in class. I will be surprised if your answers are shorter than a paragraph. (3 pts each)

1. Describe the process that led to the first observation of Pluto. In your writing, refer to the three words we've spent the last several days discussing (hypothesis, theory, and law). Be careful of using loaded words.
2. List as many reasons as you can why people support and/or dislike the decision to revoke Pluto's planetary status. You should have two lists.
3. How does what happened to Pluto support the idea that 'science has a durable, yet tentative nature?'
4. One of the main issues some scientists have with the decision is that not enough scientists voted. Why do you think this is such an issue, and how would you solve it?
5. Note that scientists are voting on how to categorize Pluto, not whether it exists. How does voting on ideas distort how scientists determine how the natural world works?
6. Far from being unbiased and objective, big changes in science are often accompanied by strong emotion and discomfort. Who is most affected by Pluto's demotion, and why is their struggle important?
7. Science is a discipline of disagreement throughout its history, the biggest changes have come with the biggest uproar. Describe an example from the history of science that has controversy similar to the Pluto decision (the books in the back cabinet provide an excellent reference).

considers how science actually works and addresses science content. Students are familiar with planets, but they still must do a great deal of abstract thinking in this activity so I think of it as nearer the abstract end of that spectrum. To more explicitly draw students' attention to key NOS ideas, I modified some of the language and questions to have students reflect on the NOS. Without these adaptations, the original activity would have been a far more implicit NOS activity.

Next year I plan to add a more concrete experience to help students wrestle with the activity and its significance. I'll take a telescope or good set of binoculars and have students gather in the evening and observe any visible planets. I'll take the opportunity to explicitly point out and discuss the different sizes of these planets and relative difficulty in finding them. I will ask students to speculate why it took astronomers so many years to discover these objects, and others that are even smaller. I will be able to refer back to this discussion during the activity about the demotion of Pluto, and address how the need arose to redefine the accepted definition of "planet" as additional objects were observed.

Summary

I have found that effectively teaching the NOS is enhanced by attending to the four pedagogical issues noted throughout the article. When planning lessons, I always think about how the NOS can be integrated. However, this does not mean that I always choose to incorporate explicit NOS instruction. Consideration of the four continua helps me decide whether or not the NOS should be explicitly integrated and, if so, how. Thus, it provides a useful approach for making better pedagogical decisions regarding NOS instruction.

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***Matthew D. Bannerman** teaches biology and physical science at Clarke High School in Osceola. Matthew previously published an article in the Spring 2007 issue of ISTJ about using inquiry to introduce units of measure. He can be reached at matthew.bann@gmail.com.*