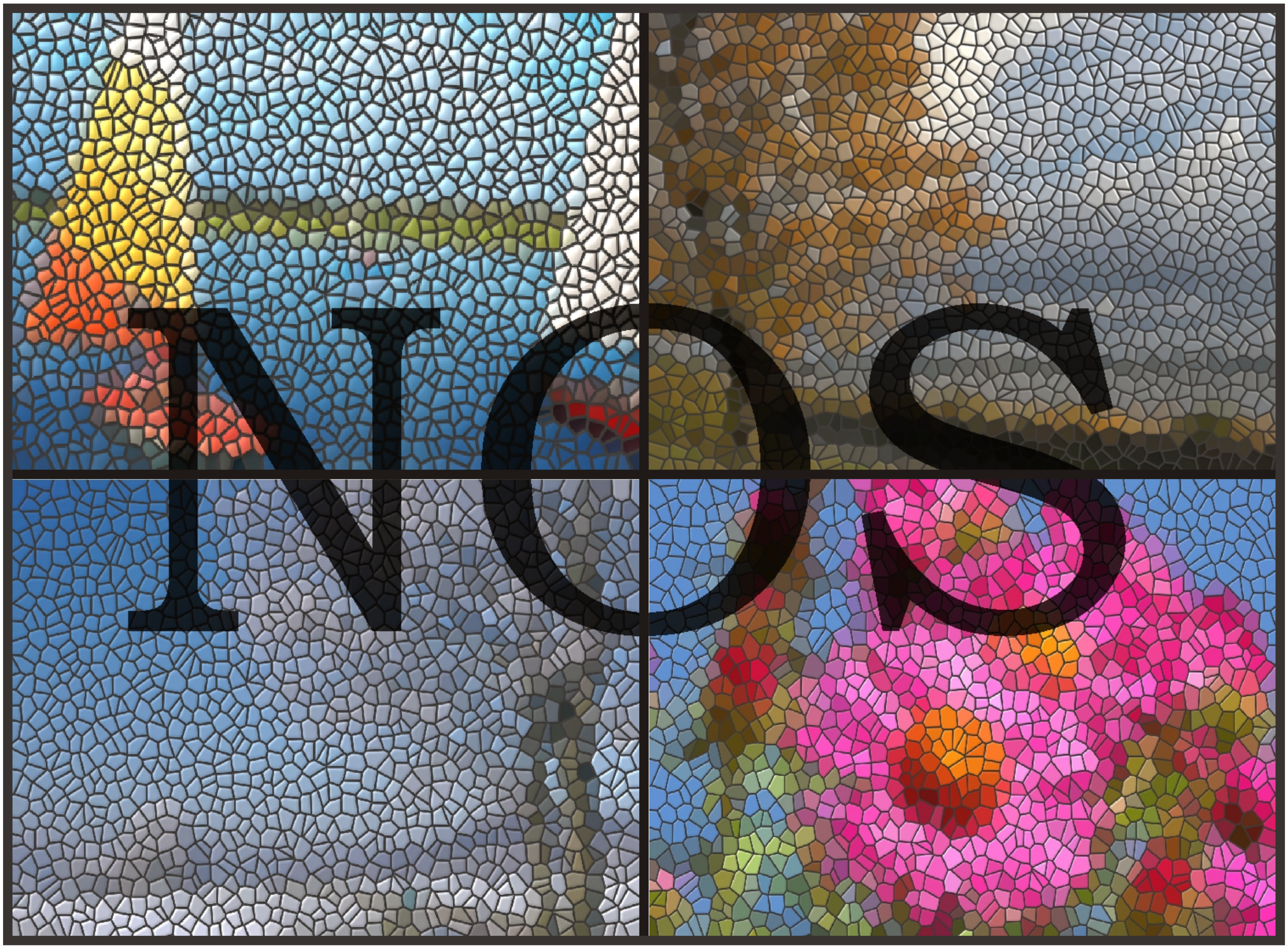

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INTEGRATING THE NATURE OF SCIENCE THROUGHOUT THE ENTIRE SCHOOL YEAR

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ABSTRACT: Secondary school students possess many significant misconceptions regarding the nature of science (NOS). Accurately portraying the NOS throughout the school year is necessary for promoting desired conceptual change. However, few teachers devote more than an isolated unit to the NOS, and rarely explicitly raise NOS issues while teaching science content during the rest of the year. This practice is problematic considering the implicit inaccurate NOS messages generally present within the science classroom. This paper discusses how to explicitly integrate accurate NOS instruction through the entire school year, and provides examples illustrating how to do so. *This article promotes National Science Education Content Standards A, E, and G, and Iowa Teaching Standards 3, 4, and 5.*

Rationales for accurately portraying the nature of science (NOS) are well documented (Clough & Olson, 2004; McComas, 1998; Matthews, 1994; McComas, 2004; NRC, 1996; McComas, Clough, & Almazroa, 1998; Moore, 1983; Shamos, 1995). Much discussion has focused on students' NOS misconceptions (Chiappetta & Koballa, 2004; Clough, 1995; Lederman, 1992; Ryan & Aikenhead, 1992) and how to overcome such strongly-held inaccurate conceptions (Clough, 1997; Colburn, 2004; Lederman & Abd-El-Khalick, 1998; Lederman & Lederman, 2004). In many science classes the NOS is explicitly addressed only in an isolated unit taught early in the school year, and students are rarely persuaded to truly abandon their deeply engrained misconceptions. Conceptual change requires time and effort, and this article presents strategies for continually addressing and assessing the NOS in a manner that enhances science content instruction.

Common ideas about the NOS considered important for secondary students include (Abd-El-Khalick, *et al.*, 1998; Clough, 2007; McComas *et. al.*, 1998; McComas & Olson, 1998):

- Scientific knowledge is tentative, yet durable.
- Science includes both a sense of discovery and requires invention.
- Scientists are human beings who are influenced by the wider culture, their prior thinking, and other factors besides the drive to learn new things.
- Basic science, applied science, and technology are distinct endeavors, yet greatly influence one another.
- Science adopts methodological naturalism resulting in rejection of supernatural explanations as scientific. Yet, by limiting itself to theoretically empirically testable ideas, science makes no claim about the existence of supernatural beings.
- While science relies on empirical evidence, scientists must make meaning of data using theory and creativity to interpret evidence.
- No universal scientific method exists. While "the scientific method" seems like a useful problem solving method, when looking at what scientists actually do/did, there is little reason to think that all scientists use(d) the same "method".
- Absolute proof is elusive–scientists cannot know if their ideas are correct, but in some cases can gain overwhelming evidence supporting their ideas leaving little room for doubt.
- Scientific theories and laws are different kinds of assertions. Theories do not become laws because they serve a different purpose for understanding the natural world.
- Scientific models are useful for working through problems and testing ideas. Models may be representations of what scientists believe to be reality or may just be useful tools.

This list is not exhaustive, yet it illustrates how NOS ideas overlap. Deep understanding of the NOS requires much more than simply being able to repeat 'tenets' concerning how science works. Students need to wrestle with these abstract ideas and connect the NOS to historical and contemporary scientific issues.

Considerations for NOS Instruction

NOS instruction should not be indoctrination. Clough (2007) suggests treating NOS ideas as questions to be wrestled with, rather than discrete pieces of knowledge to be transmitted. For example, rather than noting that science is tentative, teachers might have students wrestle with questions such as

- In what way is science tentative?
- For what reasons do we think that scientists are generating reliable knowledge?

As with all instruction, teachers must consider how students assimilate new ideas into mental structures. Simply telling students how science works or having them read about science is not enough (Rowe & Holland, 1990; Saunders, 1992). Teachers must determine what their students are thinking and design activities that lead students to more accurate understanding (Clough, Clark & Berg, 2000). However, even in model classrooms, long-term NOS conceptual change can prove difficult (Clough, 1995).

Abd-El-Khalick & Lederman (2000) note the need to make NOS instruction both explicit and reflective. Historical examples or inquiry may be used to accurately model the NOS. However, without explicitly drawing students' attention to NOS ideas, their understanding concerning how science works is not likely to be altered. Furthermore, students often interpret activities to fit with their naïve views of the NOS, even when the activity accurately portrays how science works (Tao, 2003). As with any content, teachers must continually have students reflect on their understanding. The reflection process can help students synthesize concepts and provides the teacher with insight to student thinking on which instructional decisions can be based.

Clough (2006) argues that NOS instruction would be more effective if links were continually made between NOS learning experiences that he categorizes along a decontextualized to highly contextualized continuum. Decontextual NOS instruction is that which is divorced from teaching content, and include, but are not limited to, the popular "black-box" activities. Such experiences may be used to draw out aspects of the NOS without the added difficulty of addressing science content. Contextual NOS instruction is embedded in science content instruction and might include inquiry-based learning experiences as well historical and contemporary science stories to illustrate science concepts and the NOS. Decontextualized NOS instruction engages students in cognitively challenging NOS issues without having them also struggle to understand science concepts. Furthermore, the decontextualized activities provide a concrete foundation to link contextualized NOS instruction.

To summarize, effective NOS instruction demands the following:

- NOS ideas are an explicit part of planned instruction;
- Students' attention must be explicitly drawn to NOS ideas;
- Students must be mentally engaged and reflect upon NOS issues; and
- Significant scaffolding between decontextual and contextual NOS experiences.

Additionally, teachers must closely monitor students' progress throughout the year so that NOS misconceptions can be addressed and deeper levels of understanding achieved.

Introducing the Nature of Science to Students

Lederman and Abd-El-Khalick (1998) provide several interesting activities for introducing the NOS to students. Many "black-box" activities introduce the NOS in a decontextualized manner; not specifically addressing science content, yet encouraging students to see science as a problem-solving endeavor (Kuhn, 1970). These activities provide concrete experiences that may be used to illustrate aspects of the NOS.

One simple black-box activity I use early in the year is investigating unknown objects inside of film canisters and having students work to figure out what object their canister contains. During the activity I encourage students to employ any strategies they wish, and the only rule is that they cannot open the film canisters. After students have investigated their objects, I lead a discussion regarding how the activity mirrors key aspects of doing science. This discussion, held early in the year, is designed to get students thinking about how they went about investigating the object and implications for how science works. Some questions I ask include:

- You were not allowed to open your canisters and do not know for sure what is inside. How is this like a scientist who is investigating the natural world? How is it different?
- In what ways did other classmates affect the way you investigated your canister, how you interpreted data, and the conclusions you reached? What does this imply about the value of collaboration when doing science?
- Considering that each of you approached the problem in different ways, what might we conclude about the existence of one scientific method?
- How might technology have helped your investigation?
- Some of you claimed that sound helped you determine your object. How was sound useful? How might your conclusions been different had you never heard that sound before? What does that imply about how prior knowledge and experience impacts your investigation and data analysis?
- In what way did you have to make meaning of the data you collected? How is this different than data telling you what to think?
- How did you use different pieces of evidence to support your conclusions?
- How might your ideas change if you had more time or made new observations?
- Several of you asked for empty film canisters, how did you make use of these? How do scientists use similar strategies when investigating the natural world?

Key here is making explicit links to NOS concepts taught. After discussing questions such as those above, having students compare and contrast the canister activity to "real" scientists encourages them to further reflect on how science works. I do not expect students to develop sophisticated understandings of the NOS after this one activity. Rather, I use this sort of activity to introduce students to complex ideas regarding the NOS. While important for introducing NOS ideas, black-box activities alone are insufficient for convincing students that those ideas apply to authentic science situations. In a sense, they have been introduced to the rules of the game (Yager, 1988), but need much more time and experience to truly understand and flexibly apply NOS ideas.

Addressing the Nature of Science during Content Instruction

Maintaining pressure on students' naïve NOS conceptions is necessary to promote long-term conceptual change (Clough 1997). Classroom activities may often be easily modified to accurately and explicitly promote the NOS. The example below illustrates how inquiry-based activities may be used to teach both science content and the NOS. However, during these activities, teachers must pose questions to generate discussion of key NOS ideas (Clough & Olson, 2004).

A common middle school activity has students follow a step-by-step method for investigating the effect of hard water on soap. This sort of experience raises the question, "Where's the Science?" (Penick, 1991). Rather than following the text, I pose the following question to my 7th graders, "How does hard water affect soap?" Students propose ideas and I ask, "How could we find out?" From the resulting discussions, students gain greater understanding of what it means to "do science". I do not force students to use the same procedures and the data collected is often quite ambiguous. A detailed description of how I implement this activity is beyond the scope of this article. However, the following illustrates how laboratory activities and post-lab discussion may be used to explicitly draw students' attention to the NOS.

In one of my classes, all but one pair of students interpreted the collected data in a manner opposite from how hard water should affect soap. During the discussion that ensued (using questions similar to those appearing in the bulleted list above) we addressed interpretation of data, consensus building, social aspects of science, etc. Furthermore, I asked questions that encouraged students to reflect on the decontextualized activities they had previously completed, such as the canister activity. For instance:

- What similarities do you notice between how you conducted this investigation and the canister activity from earlier in the year?
- When discussing the canister activity, we noted that you had to interpret data and that data did not "tell" us what to think. How does this NOS idea apply to this investigation?

These kinds of questions can be used with nearly any activity, even with cookbook activities to draw students' attention to how they distort the NOS.

After taking some time to discuss the NOS, my students moved forward with their research and began testing different salts and different concentrations and their effects on soap bubble formation. During these investigations much of their data was interpreted to be inconsistent with their previous thinking and the students were forced to re-evaluate their conclusions. I remember one student, not wanting to admit being wrong, saying, “Couldn't we all be making the same mistake? Maybe the salts are bad?” This presented an excellent opportunity to discuss objectivity and how science, by nature, is theory-laden (i.e., Prior thinking affects how we interpret new evidence). Students, like scientists, resist abandoning tightly held ideas and will search for error-based explanations of anomalies.

The language teachers use while teaching science content is important for accurately conveying the NOS (Clough & Olson, 2004; Munby, 1976; Zeidler & Lederman, 1989). Explicit attention must be paid to the use of words such as “prove,” “tell,” “discover,” and others. Students often interpret “prove” to mean absolute truth; “tell” to mean data need not be interpreted, and “discover” akin to finding a lost item. I avoid using these words, or explain what I mean by them when I do use them. When students use words such as these, I ask them to explain what they mean by the word. By continually requiring students to explain what they mean by these words, and drawing students' attention to more accurate phrases such as “provide evidence for,” “interpret,” and “developed the idea,” students learn about the NOS, why some words are problematic for conveying how science works, and they begin intentionally using more accurate phrasing.

Additionally, addressing inaccurate NOS messages in the students' textbook should be done throughout the school year when teaching science concepts. Science textbooks sanitize the scientific process and almost always distort how science works. The following two examples illustrate how problematic textbook portrayals of the NOS may be addressed while teaching science content.

> Your textbook states that Millikan 'discovered' the charge on an electron. What might “discovered” mean in this context? In what sense does the word “discovered” accurately convey what Millikan did?” In what sense does the word “discovered” distort what Millikan did?”
>
> Your textbook has referred to cell theory, evolutionary theory, and atomic theory. What does the word “theory” mean and how does it apply to each of these science ideas?

Addressing the nature of science using real science episodes

Despite teachers' best efforts, students can still dismiss “black-box” and laboratory experiences as not reflecting authentic science (Clough, 2006). Having students meaningfully reflect on their experiences and how those experiences might compare to real science is important, but is not enough. If students are never exposed to authentic science, they might dismiss NOS lessons as not reflecting real science (Clough, 2006).

Providing historical and contemporary examples of science in the making is important see that the NOS concepts they have been learning apply to real science. Matthews (1994) provides several arguments for including the history of science in the science curriculum. Historical episodes appropriate for secondary school students have appeared in *The Science Teacher* (Abd-El-Khalick, 1999; Clough & Olson, 2004) and elsewhere (Bowden, 1997; Centre for Science Stories, 2008). I have used historical anecdotes concerning phlogiston, gas laws, plate tectonics, geocentricism, atomic theory, the periodic table, evolution, DNA, as well as biographical information on many scientists.

While students contemplate these historical episodes, I use carefully posed questions to help students perceive the NOS within the stories (Abd-El-Khalick, 1999; Clough, 1997). I explicitly address the NOS by asking students to compare and contrast these episodes with the black-box activities and laboratory investigations we perform in class. This important reflective component, when coupled with short stories or anecdotes, encourages students to connect what they are reading about real science to the lessons they have already learned about how science works. When reading about real scientists, students cannot easily dismiss the NOS ideas being discussed as not representing authentic science (Clough, 2006).

Putting it all together

I intentionally use several decontextualized NOS activities throughout the year. The activities I choose often reflect the content I am trying to teach. One example that comes to mind is teaching students about the development of the Big Bang Theory. I have the students read a short story about how two different camps (Big Bang and Steady-State) were working to explain the origin of matter, and both groups needed to be able to explain why the universe was expanding. Each group came to different conclusions for explaining the data–one claiming the expansion was due to the initial explosion, the other citing continual creation of elements as the cause. At this point I have the students consider how what we believe to be true about the world affects the explanation we create to account for data. Yet, the thinking I am asking the students to do is extremely abstract, so before having them read the short story, I have the students experience the notion of theory-laden interpretations by using gestalt switches.

A common example of a gestalt drawing is the duck/rabbit (Figure 1). When this picture is held one way, the image is clearly a duck head, yet, when turned 90 degrees, the image is more of a rabbit head with the beak becoming ears. I have half of my students face the back of the room and show the other half the picture of a rabbit. Then I switch their roles, showing the second group the duck orientation. I then ask the students to explain what they saw to the other half of the class. At some point during the discussion I tell the students that each group viewed the exact same piece of paper, then ask, “How can you account for each group's markedly different interpretations?" As the discussion ensues, I am asking students to elaborate on their thinking, posing carefully worded questions to push student thinking, moving around the room, and waiting after I ask questions and after students provide ideas. I do my best to not reject student ideas, but through questioning help the students see how their thinking might be flawed. By giving students plenty of think-time and not simply telling them how to think, I am encouraging students to engage deeply in critical thinking processes.

Because I have students consider how their prior thinking can affect their interpretation of data in a decontextualized situation, they are able to meaningfully engage in wrestling with the NOS ideas without having to worry about difficult content to learn. Furthermore, by having students wrestle with these ideas before having them read the short story about the expanding universe, I can ask them to reflect on the story and connect it to the duck/rabbit drawing by asking, "How does the different thinking of each camp in the story compare to each group's view of the duck/rabbit picture?" Additionally, I ask the students to reflect on how their own assumptions and thinking has affected *their* interpretation of data in the past. With my 7th grade class I might draw their attention to the soap lab they had conducted earlier in the year.

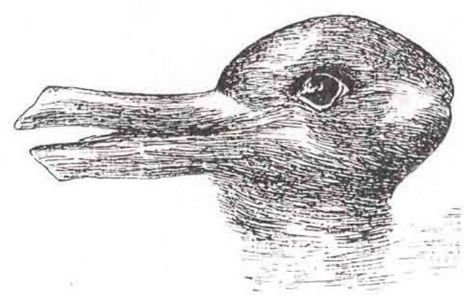
Assessing Student Understanding

Due to inherent abstraction concerning NOS concepts, assessment of student NOS understanding is difficult. The VOSTS instrument developed by Ryan & Aikenhead (1992) is too complex to accurately assess what many middle level students know, but can work well for high school. However, it requires teachers to choose which of the 114 items to use, and understand which answers are more appropriate. The VNOS (Lederman et. al., 2002) is frequently used in science education research, but the time required to administer and assess may be prohibitive.

For more information about the VOSTS instrument, and to access the VOSTS student survey, visit:
http://www.usask.ca/education/people/aikenhead/vosts.pdf

I have assessed my students NOS understanding using ratings (e.g.: science is objective: rate from 1-10 and explain), as well as asking questions that address the NOS on exams. One method I have found useful is using writing stems such as: "Science is…". This open-ended assessment keeps students from dogmatically responding to specific questions. I have also used a 25-question NOS assessment downloaded from the Evolution and Nature of Science Institute website (2006) which I modified from a simple true/false response assessment to also include the following choices: "both true and false" and "I don't understand the question." I also require students to provide an explanation for their choice.

FIGURE 1
Duck and Rabbit image used to demonstrate a Gestalt Switch.



Jastrow, 1899.

Assessing the NOS when students begin to develop sophisticated understanding becomes more and more difficult-- no longer are black and white responses sufficient. As noted in the beginning of this article, scientific knowledge *is* tentative, yet there are reasons to think that some of our ideas are not likely to change. Importantly, assessment of student understanding must be ongoing. Every time students discuss, write about, or answer questions concerning the NOS teachers gain new perspective on which they can plan future instruction.

Final Thoughts

Continued explicit and accurate NOS instruction is important for students to truly understand NOS concepts. Kruse (2008) notes that 7th grade students showed improvement during one semester of instruction, but showed even greater improvement during the second semester of continual integrated NOS instruction. Many teachers recognize the importance of teaching about the NOS, but allocate only one unit or a few weeks for NOS instruction. While students may be able to pass the unit test, their fundamental thinking about the NOS has probably not been significantly altered. The NOS needs to be integrated throughout the entire year through use of decontextualized (i.e. NOS instruction not tied to science content), contextualized (i.e. NOS instruction linked to school science content instruction), and highly contextualized (NOS instruction linked to the authentic workings of scientists) experiences. However, these experiences alone do not demand that students wrestle with NOS issues. Teachers must continually work to draw explicit attention to NOS concepts and encourage students to reflect on their thinking by asking carefully worded questions and providing students with the appropriate scaffolding to these complex ideas.

The importance of continually addressing the NOS becomes apparent when considering what implicit messages are sent by the way science is taught. While school based inquiry activities more accurately model how "real" science works, they almost always differ in important ways from authentic science. This difference is something to be discussed and wrestled with by students. Also, there is a time and place for cookbook laboratory activities (e.g., when safety is of concern), but if the inaccurate NOS messages are not addressed explicitly, students may grow even more entrenched in their misconceptions and dismiss the accurate NOS instruction they have had.

By *continually* addressing and assessing the NOS throughout the year, students come to better appreciate the scientific endeavor. They begin to see science as more than verification and memorization of facts. As students' understanding of the NOS grows, they move closer to what the National Research Council (1996) would call a scientifically literate individual. Strategies and activities for teaching the NOS are useful, but we must understand that difficulties in conceptual change cannot be addressed with only isolated NOS activities. Extensive, explicit, accurate and *sustained* NOS instruction is necessary.

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