More Than a Human Endeavor

Teaching the nature of science at the elementary level

By Joanne Olson

The nature of science addresses what science is and how it works, exploring questions such as: How is science similar to and different from other human endeavors? How durable is science knowledge? How do scientists do science? In what ways do culture and society affect scientists' work? What are the differences and similarities between basic science, applied science, and technology? Because the nature of science (NOS) may entail some sophisticated issues, most efforts aimed at improving students' understanding of the NOS have focused at the secondary level and higher, when students are older and more likely to comprehend these complex issues. Examining the National Science Education Standards clearly shows that most NOS standards issues are directed toward students in grades five and higher. The K–4 recommendations focus on science as a human endeavor, but what that means is problematic when one considers that history, mathematics, writing, and other disciplines are also human endeavors.

Another issue is that, by the time they have reached middle school, students often have profound misconceptions about the NOS (Ryan and Aikenhead 1992; Clough 1995). Figure 1 lists a few of these more common and tightly held misconceptions. What this means is that how science is taught in elementary school has a potentially profound impact on students' developing notions of the NOS. For example, when students are required to follow a step-by-step method for all classroom science activities, students understandably think this rigid approach is required when doing science. When teachers make statements like "What does the data tell you?" and "What does that prove?" students come to wrongly see scientific thinking as requiring little creativity and its results as absolutely certain knowledge. When students are assessed primarily on science vocabulary and definitions, they perceive science to be a body of facts to be memorized.

Figure 1.

Common NOS misconceptions exhibited by secondary school students (Ryan and Aikenhead 1992; Clough 1995).

- Scientists must follow a linear step-by-step scientific method.
- Good scientists are completely objective in their work.
- Scientific knowledge is discovered, much like finding a lost physical item.
- All scientific work is experimental.
- Data tells scientists what to think.
- Doing science requires little creativity.
- The scientific community is quickly convinced by new evidence.

Clough and Olson (2004) point out that because of the strong messages curriculum materials and methods convey, science teachers are always teaching the nature of science, whether or not they intend to do so! So the question is not whether elementary teachers will teach their students about the NOS, only what about the NOS will be conveyed. Helping young children avoid developing deeply held misconceptions and promoting developmentally appropriate NOS ideas will establish a foundation for students from which they will later develop more accurate and sophisticated NOS understanding.

The good news is that K–4 teachers can significantly influence students' development of accurate ideas about the NOS. The following are important NOS ideas and practical K–4 classroom teaching strategies to help teachers avoid inadvertently perpetuating these misconceptions.

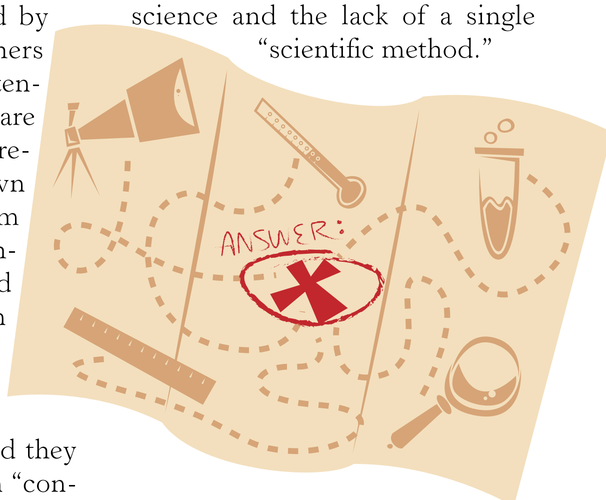
Science is a creative endeavor, and many ways exist to do science.

Don't teach or convey that scientists follow a step-by-step "scientific method." When I took a course in the nature of science, I remember how surprised I was to learn that scientists don't follow a linear, step-by-step method. The physicist and Nobel Laureate, Percey Bridgeman, is often quoted as saying that, "Science is doing your damnedest, no holds barred." Unlike the rigid method most of us were taught when we were science students, scientists use their prior knowledge, novel questions, expectations, past experience, colleagues, creativity, and available funding and technology to help shape the procedures they use. Much of science does not, and cannot, rely on controlled experiments, yet it still provides solid conclusions regarding how the natural world works.

The mistaken notion of a "scientific method" is an important issue. My colleagues and I recently conducted a study with college students (Olson, Clough, and Vanderlinden 2007). We found that when students have the misconception that science must follow a linear "scientific method," they are likely to also wrongly hold the following views:

- Science is not creative. This is a reason students cite for choosing not to major in science (Tobias 1990).
- Research that does not follow what students perceive as the scientific method is bad science, and they therefore easily dismiss biological evolution, cosmology, age of the Earth, and other areas of scientific research.
- Precisely following the scientific method leads to proven truth (an over-reliance on science knowledge as the "only" way of knowing).

Instead of teaching a step-by-step method (often implied by cookbook activities), teachers can focus young students' attention on clarifying what they are trying to find out and then creatively developing their own procedure that will help them answer their question. Teacher support will be required to help students decide on the materials they will need, the amount of time that will be required, ensuring any testing is done fairly (a word they understand more easily than "controlling variables"), and relevant safety issues. Except in situations that have safety concerns, encourage students to try their ideas, even if their way is very inefficient or could be better studied another way. By having students make decisions, they experience science in a far more accurate manner. After investigations, teachers should draw students' attention to the multiple ways that were developed to try to answer their questions and illustrate that scientists have to make these same kinds of decisions. Following an investigation of fish, my third- and fourth-grade students enjoyed reading about Jane Goodall, who used similar kinds of observations (not experiments!) to become a leading expert on chimpanzees (Goodall 2001). Older elementary students also enjoy *The Value of Believing in Yourself: The Story of Louis Pasteur* (Johnson 1976), followed by discussions about how creativity is so important when trying to solve problems. See Figure 2 for examples of questions that are helpful in drawing students' attention to creativity in science and the lack of a single "scientific method."



Data doesn't speak; instead, scientists have to develop an idea that makes sense of data.

This is a crucial distinction! When we say to students, "What does the data tell you?" or "What do your observations show you?" we unwittingly send the message that the answers are right in front of the student. If this was the case, all students should come up with the same answer. The history of science is filled with examples of scientists looking at the same data but developing different explanations for those data. The important NOS idea that science is

Figure 2.

Questions for students.

Grades K–2:

- What did you decide to try?
- How is that different than what other groups tried?
- What other ways can you test that idea?

Grades 3–4:

- How many ways did our class develop to test this idea?
- How do we know what way we should use to test an idea? (Notice that we often don't know if problems will occur until we are trying something!)
- How do you think scientists figure out how to test their ideas?
- Notice that Jane Goodall is not doing experiments. What did she choose to do to help her answer her questions?

a human endeavor means far more than people doing science—scientists are human and must wrestle with ideas and data that are not at all straightforward. Making sense out of the very messy natural world isn't easy for scientists, and it's not easy for our students. We can greatly help our students if we say, "What ideas do you have about this?" or "What do you think might be happening here?" Such phrasing enables students to feel more comfortable putting forward their ideas even when they may not be completely confident in those ideas. That's good scientific thinking! We can then use those tentative ideas to do further tests, discuss them with others, or try a new idea.

Knowledge in science cannot be "proven" or absolutely "true."

Avoiding the words *prove* and *truth* is an important way to accurately portray scientific knowledge. In science, we cannot ever know for certain that our ideas are absolutely correct. Moreover, we do not have access to all instances of a phenomenon in order to claim that our idea is "proven." While it is very easy to say "Prove it!" to a student, using such language conveys to our students that science is about proof. Instead of asking students to prove their ideas, ask students to find evidence for their ideas or support their ideas.

K–4 students are not yet ready to study the status of scientific knowledge, but not having the words *prove* and *truth* tied to science class will certainly help them later on when they learn why accepted scientific knowledge means those ideas are supported by a great deal of evidence and reasoning.

Not every activity in science is an "experiment."

Use the term *experiment* when students are controlling variables and running tests to determine the influence of certain variables on a phenomenon. Otherwise, call it an *investigation*. This distinction is important because many scientists do not do experiments, yet they are still doing good science. Some of our students may not like experiments, and if they perceive that scientists only do experiments, they may begin to dislike science. In addition, some students may think that only experimental science is good science, and may then reject many science concepts that are not based on experimental work.

Using terms carefully when teaching is important for teachers of all grades. However, teaching students the distinction between investigations and experiments is more appropriate above grade three. To teach this distinction, I involve students in numerous types of investigations, including experiments. I ask students to look at what they did, and we write the steps of each activity on the board. We look at what makes the experiment different than the other activities, and students will notice that one activity involved "fair testing" where we keep as much as possible the same while changing just one thing at a time. I label that an "experiment." We then read short autobiographies of scientists, and I ask students how the scientist tried to answer his or her question. We then decide if he or she was doing an experiment or another type of investigation—such as making detailed observations.

Not every activity in science starts with a hypothesis.

"Hypothesis testing" science is typically associated with an experimental setting, but a scientist making a hypothesis has a rich background that provides a foundation to make very informed judgments about what is to be expected. In fact, this expectation can cause the scientist to select some procedures over others, accept certain data while rejecting others, and favor certain kinds of explanations. When students are asked to make a hypothesis in a classroom setting, they very rarely have enough background knowledge to determine in advance what will occur. In addition, they are rarely given the opportunity to use their own ideas to inform the procedures that are used to investigate the phenomenon. When elementary teachers ask young children to make a hypothesis, what they unwittingly convey is that a hypothesis is a guess. When students make hypotheses under these conditions, they usually guess what the outcome will be, are frustrated when they are wrong, erase their original guess, and leave the experience feeling that science is difficult, unpredictable, or focused on right answers.

Instead of making hypotheses in advance, I find that students are far more successful when they have rich experiences with the phenomenon first and then make predictions about further investigations that use the initial experience. For instance, if we have been exploring water flow on a stream table, I can then ask students what they think might happen if we made the water flow faster.

Using the word *prediction* instead of *hypothesis* helps makes connections between language arts (where we predict what will happen next in the story), mathematics (where we predict the next sequence of numbers based on a pattern), and science (where we explore a phenomenon and then predict what will happen when we make changes or test an idea). The process of prediction is a critical-thinking skill that spans disciplines and is not exclusive to science. Also, *hypothesis* is so closely associated with the inaccurate *guess* definition that I find it difficult for students to separate how the term is used in science with the way it is so commonly misused in our culture.

Connecting to the Standards

This article relates to the following *National Science Education Standards* (NRC 1996).

Content Standards

Grades K–4

Standard G: History and Nature of Science

- Science as a Human Endeavor

Assessment

Avoiding the development of significant misconceptions about the nature of science often requires that elementary teachers use language very carefully when teaching science. Avoiding words like *prove* and *truth* and asking for students' ideas rather than what the "data shows" can help students better understand more explicit instruction in the nature of science in later years. For this reason, assessment of young children's knowledge of the nature of science is largely of a formative nature. I recommend listening carefully to children's talk and paying close attention to how students use words such as *experiment* or *prove*. If these words are used inappropriately, I gently model the correct use of these terms in my responses to students. In summative assessments, I may ask students to develop more than one way to test a given question. I may pose a scenario where two children look at the same data and come to different conclusions and ask the students to write why they think that might happen and what they think the two children should do next. Another consideration is to broaden requirements for science fairs from only allowing experimental science to including observational science and other ways of answering questions about the natural world. Even if students choose to conduct experiments, try to avoid a "scientific method" display and instead ask students to report exactly what happened. You'll find that the real investigation is far more interesting and convoluted than a linear method suggests—just like the real work of scientists!

Worth the Effort

Students do need to understand that science, like other disciplines, has been done by many people in many cultures. In addition to these explicit lessons, however, we can do much to help K–4 students avoid developing common misconceptions about what science is and how it works. Teaching that science is done in many ways and that the ways we do science depend on the questions we are investigating helps students experience science as the highly creative endeavor that it is. By using language very carefully in our teaching, we can help our students avoid tangling words like *proof* and *truth* when thinking about science. We can help our students make careful predictions when they have sufficient background experience to do so. Importantly, we can help maintain our students' interest in science by connecting it with other human endeavors that also use creativity, seek patterns, make predictions, and investigate problems. In doing so, our young students can see the natural world as accessible to them and engaging of their natural curiosity and creativity.

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