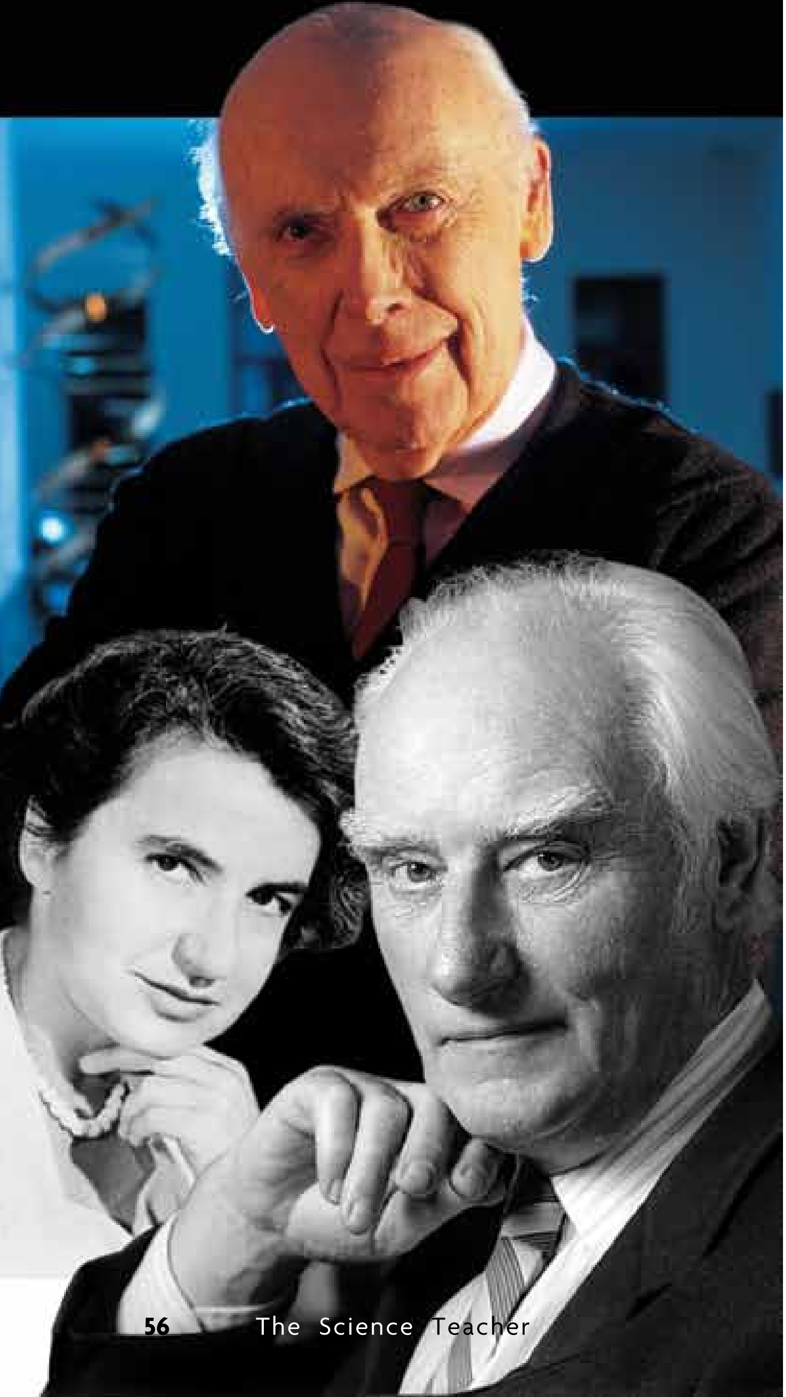
Teaching and Assessing the Nature of Science

How to effectively incorporate the nature of science in your classroom



Left: **Rosalind Franklin** (photo courtesy of Jewish Chronicle Archive)
Top: **James Watson**
Right: **Francis Crick** (photo courtesy of Marc Lieberman)

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Understanding the nature of science (NOS)—what science is and how it works, the assumptions that underlie scientific knowledge, how scientists function as a social group, and how society impacts and reacts to science—is prominent in science education reform documents (Rutherford and Ahlgren 1990; AAAS 1993; McComas and Olson 1998; NRC 1996; AAAS 2001) and state science standards (McComas, Lee, and Sweeney 2009). The preamble to NSTA's (2000) position statement on NOS begins by asserting that "all those involved with science teaching and learning should have a common, accurate view of the nature of science."

There are many reasons why accurately and effectively teaching NOS is so important (Figure 1; Matthews 1994; McComas, Clough, and Almazroa 1998). Moreover, the history and nature of science demonstrate scientists' conceptual struggles in trying to understand the natural world. This can help science teachers appreciate students' conceptual journey to comprehend contemporary science ideas; it can also help students realize they are not alone in their struggles. However, despite the overwhelming agreement regarding the importance of accurately and effectively teaching NOS, much remains to be done to achieve this goal in elementary through postsecondary science education.

Though many NOS issues are not entirely settled, much agreement does exist regarding ideas worth teaching and learning in science education. However, providing a list of NOS ideas for science teachers to address can inadvertently result in it being seen as something to be transmitted to—rather than explored with—students. We want students to truly understand NOS, not simply know particular NOS ideas.

As Eflin and colleagues (1999, p. 112) state, "Just as science educators stress that science is more than a collection of facts,

FIGURE 1

Reasons for accurately and effectively teaching the nature of science.

This promotes
- an appreciation of science;
- an increased interest in science classes and science careers;
- greater engagement in learning about biological evolution; and
- better understanding of science's strengths and limitations, the role of science in social decision-making, and many science concepts.

we emphasize that a philosophical position about the nature of science is more than a list of tenets." Because science is such a complex and varied activity, rather than listing specific NOS ideas students should learn, NOS issues should instead be addressed as questions (Figure 2; Clough 2007). This encourages both teachers and students to think more deeply about the contextual nature of NOS ideas and promotes reasoned thinking that takes into account those contexts.

This article illustrates how to accurately and effectively teach NOS as part of everyday science instruction.

Planning for and teaching NOS

Effective NOS instruction doesn't just happen by chance. Teachers who genuinely want students to accurately understand NOS see it as a crucial goal in science education. Thus, they frequently express it as an objective in their lesson plans, looking for ways to promote student actions like those in Figure 3. Sometimes, focusing a lesson exclusively on NOS is appropriate. In these instances, teachers may have students take part in common black-box and puzzle-solving activities or readings that focus on NOS (see "On the web"). But for students to truly value and understand NOS, it should also be planned for in the context of everyday science content so students can see how what they are learning applies to authentic science (Clough 2006).

Explicitly planning for and drawing students' attention to NOS does not mean lecturing to them about it. Rather, when exclusively focusing on NOS or addressing it in the context of laboratory activities, videos, reading assignments, and interactive science content presentations, try asking questions such as those in Figure 4 (p. 58). These kinds of questions explicitly raise NOS ideas and can be used in most any lesson to get students thinking about how science and scientists work. Moreover, asking these kinds of questions can bolster students' understanding of NOS ideas without monopolizing class time.

FIGURE 2

Nature of science questions worth exploring in science education.

- In what sense is scientific knowledge tentative? In what sense is it durable?
- To what extent is scientific knowledge based on or derived from observations of the natural world? In what ways is it based on reasons other than observational evidence?
- To what extent are scientists and scientific knowledge subjective? To what extent can they be made less subjective?
- To what extent is scientific knowledge socially and culturally embedded? In what sense does scientific knowledge transcend particular cultures?
- In what sense is scientific knowledge invented? In what sense is it discovered?
- How does the notion of a scientific method distort how scientists actually work? In what sense are particular aspects of scientists' work guided by protocols?
- In what sense are scientific laws and theories different types of knowledge? How are they related to one another?
- How are observations and inferences different? In what sense is an observation an inference?
- How is the private work of scientists similar to and different from what is publicly shared in scientific papers?

FIGURE 3

Student actions consistent with understanding the nature of science.

Students will

- Describe the differences and interactions between basic science, applied science, and technology.
- Articulate why science explains natural phenomena in naturalistic terms with no recourse to the supernatural.
- Provide arguments against a universal scientific method.
- Explain how imagination and creativity are crucial in doing science.
- Explain how scientists develop ideas to account for data, and how data does not tell scientists what to think.
- Justify why well-supported science ideas, though durable, may be re-examined, modified, and replaced. Explain why this possibility of change is a strength of science.
- Accurately explain how scientific laws and theories are different types of knowledge, yet relate to one another.
- Provide examples illustrating that science has both a collaborative and competitive character.
- Identify inaccurate stereotypes of scientists.
- Provide examples of how science and society impact one another.

FIGURE 4

Teacher questions that encourage students to think about the nature of science.

- How might this black-box activity be similar to and different from real science?
- How does your work in this laboratory activity illustrate that you did not follow a step-by-step scientific method? How is this similar to the work of scientists?
- How does the work of [insert scientist(s)] illustrate that data does not tell scientists what to think, but instead that creativity is part of making sense of data?
- In science, the word *theory* is often wrongly interpreted as meaning *guess, opinion,* or *a not well-substantiated claim*. How does that meaning not capture the confidence we have in kinetic molecular theory? (**Note:** This question is most effective when asked after students have studied and are coming to understand the power of the theory. It can be asked in the context of any well-established theory, such as atomic theory, the theory of plate tectonics, the theory of evolution, and so on.)
- How does the DNA work of James Watson, Francis Crick, Maurice Wilkins, Rosalind Franklin, and Linus Pauling illustrate that doing science involves both collaboration and competition?
- Consider the model of the atom and the evidence that supports it. How does this work illustrate that science ideas are developed to account for data (i.e., data doesn't tell scientists what to think)?
- In what ways does this portion of your textbook distort what real science is like? (**Note:** Unfortunately, this question can be asked at most any point in typical science textbooks.)
- How does the process by which science came to understand the link between asteroids and dinosaurs illustrate that it requires creativity and does not follow a linear process (see "On the web")?
- What prior knowledge did you use in developing your laboratory procedure and analyzing your data? How does this illustrate that scientific theories guide researchers in determining what questions to ask, how to investigate those questions, and how to make sense of data?

Assessing students' understanding

Though these recommendations ensure that NOS is a consistent theme in your science course, incorporating NOS questions as part of your assessments throughout the school year is also crucial. As Dall'Alba and colleagues (1993, p. 633) state, "Assessment gives clear messages to students about what is important in the subject."

To begin, determine students' prior ideas about NOS early in the school year to help you plan for instruction more effectively. There are several ways to accomplish this, such as using the Science Knowledge Survey, the Student Understanding of Science and Scientific Inquiry Questionnaire, or items from the "Views on Science Technology Society" (see "On the web").

Another approach is an engaging card-exchange activity that introduces students to NOS issues while providing the teacher with an overview of student thinking (Cobern and Loving 1998). In this activity, the teacher distributes cards describing a variety of views regarding scientists and how science works (see "On the web"). Students then exchange cards with one another in an attempt to acquire a set that best represents their NOS views. After several iterations, students use their final set of cards to write a statement summarizing these views. In addition to providing teachers an understanding of their students' thinking, these preassessments introduce students to what NOS entails, raise important NOS issues that will be revisited throughout the course, and convey to students the importance of NOS in science education.

Once you understand your students' preconceptions, begin incorporating NOS instruction at appropriate times to create dissatisfaction with students' misconceptions and provide more accurate alternatives (Clough 1997; Clough 2004). The questions in Figure 4 not only draw students' attention to NOS and get them thinking about particular issues, but also serve as formative assessments that inform teachers of their students' developing NOS views. These kinds of questions should be asked as part of interactive presentations of science content (e.g., laboratory activities, videos, readings). Thus, learning to ask questions (Figure 4) as a normal part of instruction is key to effectively understanding your students' NOS thinking, emphasizing the importance of their learning about the NOS, and planning further NOS instruction.

Formally assessing students' understanding of NOS alongside their understanding of science content is important; this makes clear that NOS is an important part of their science education and should be taken seriously. During my years teaching high school biology and chemistry, I always included NOS questions—such as those in Figure 5—on laboratory reports and unit and final exams. Teachers who use multiple-choice exams can create those kinds of questions, but context and important nuances are almost always lost. Regardless of how you summatively assess students' NOS understanding, they will realize that it is an important goal in science education and will be assessed throughout the course.

Worth the effort!

Shamos (1995) notes that understanding NOS should be a primary goal of science education because citizens apply their NOS views—whether accurate or not—when assessing public issues involving science and technology. For instance, Rudolph (2007) argues that some business and political groups exploit the public's misunderstanding about how science is done to create doubt about global warming—a tactic also used by opponents of biological evolution. These and other compelling arguments demonstrate that NOS should be accurately and effectively taught in all science courses, and not included as an add-on when time permits. Figure 6 (p. 60) presents a list of resources that are useful for learning about NOS and accurately and effectively teaching it to students.

Teachers can be assured that their efforts will, over time, be successful. Secondary students can develop accurate understandings of NOS (Lederman and Lederman 2004) and the strategies advocated in this article can result in long-term student understanding (Clough 1995). I continue to receive e-mails from former students, some of whom were in my classes over 15 years ago, who often remark that they remember and apply what they learned in my class about NOS. Teaching and assessing NOS is definitely worth the effort! ■

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On the web

Asteroids and Dinosaurs: Unexpected Twists and an Unfinished Story: *http://undsci.berkeley.edu/article/0_0_0/alvarez_01*

Cards describing a variety of views regarding scientists and how science works: *http://webspace.oise.utoronto.ca/~benczela/NofSCardExchange.pdf*

Common black-box and puzzle-solving activities: *http://undsci.berkeley.edu/teaching/68_activities.php*

Readings that focus on the nature of science: *http://undsci.berkeley.edu/resourcelibrary.php*

Science Knowledge Survey: *www.indiana.edu/~ensiweb/lessons/sci.tst.html*

Student Understanding of Science and Scientific Inquiry Questionnaire: *www.ied.edu.hk/apfslt/v9_issue1/liang/liang8.htm#a*

Views on Science Technology Society instrument: *www.usask.ca/education/people/aikenhead/vosts.pdf*

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FIGURE 5

Example questions for laboratory reports and exams.

- Question on an exam addressing biological evolution: Why is an understanding of the nature of science important when looking at the biological evolution, creation, and intelligent design public education controversy?
- Question to be answered in a cell biology laboratory report: How does the "Plant and Animal Cells" lab demonstrate that theory must precede observation?
- Question on a biology exam addressing genetics: In our genetics unit, you learned that at one time scientists, looking at the same data, disagreed whether DNA or protein was the genetic material. What do this and similar kinds of disagreements about the meaning of experimental data illustrate about how science works?
- Question on a chemistry exam addressing conservation of mass and balancing chemical equations: Science textbooks often claim that scientific laws are "discovered" rather than "created." Using the conservation of mass law as an example, critique this claim.
- Question on a chemistry exam addressing gases: People often wrongly think that scientific laws are superior to scientific theories. Use what you have learned about gas laws and kinetic molecular theory to correct this misconception.
- Question on an exam addressing stoichiometry (Clough and Clark 1994): List and defend three ways that your laboratory work to determine the products of the following reaction accurately portrayed the nature of science (NOS). List three ways it did not accurately portray the NOS

$$NaHCO_{3\,(aq)} + CaCl_{2\,(aq)} \longrightarrow \underline{\qquad\qquad}$$

FIGURE 6

Teaching resources.

Resource	Description
University of California Museum of Paleontology. 2011. Understanding science: How science really works. *http://undsci.berkeley.edu/index.php*	A National Science Foundation (NSF)–supported project and a must-view website for science teachers of all grade levels!
Illinois Institute of Technology and National Science Foundation. 2011. Project ICAN: Inquiry, context, and nature of science. *http://msed.iit.edu/projectican*	An NSF-supported project for improving inquiry and nature of science (NOS) instruction.
Clough, M.P. 2011. Story behind the science: Bring science and scientists to life. Iowa State University. *www.storybehindthescience.org*	An NSF-supported project with stories that help science teachers improve their NOS understanding.
Clough, M.P., and J. Taylor, eds. 2008. *Iowa Science Teachers Journal.* 35 (2). *www.iacad.org/ists/ISTJ/issues/35/2_spring_08/index.html*	Special issue with activities for teaching NOS in the context of science content.
Metz, S., ed. 2004. *The Science Teacher* 71 (9).	Special issue on how the history of science and NOS improve students' science understanding.

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