Nurturing the Nature of Science

Integrating the nature of science into the existing curriculum

Carolyn Reeves, Debby Chessin, and Martha Chambless

Lise Meitner (November 17, 1878–October 27, 1968).

Science educators are able to incorporate into their teaching only a small fraction of the knowledge that exists about the natural world. This means the selection of topics for school curricula must be deliberate and thoughtful. Key scientific concepts all students should know have been identified by several major national efforts, including the *Benchmarks for Science Literacy* (AAAS 1993) and *National Science Education Standards* (NRC 1996). Both emphasize helping students understand the history and nature of science, including what science is, how it works, and how it differs from other ways of knowing.

Science works according to time-tested rules and methods that, among other things, attempt to filter out personal biases and extraneous variables during research. Students need to understand these rules in the same way that basketball players need to understand the rules of their game.

Characteristics of the nature of science

"Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical argument, and skepticism, as scientists strive for the best possible explanations about the natural world" (NRC 1996, p. 201). Explanations compose the bulk of scientific knowledge, and the standards that apply to explanations are a significant part of the nature of science. Not everyone agrees on what to teach about the nature of science, but the work of several researchers provides some fundamental ideas upon which most educators would agree. Rubba and Anderson (1978) enumerated six characteristics of scientific knowledge, proposing that it is:

- amoral (neither good nor bad, unless it is applied by technology),
- creative (a product of human imagination and intelligence),
- tentative and developmental (never absolutely proven),
- parsimonious (tendency to favor simplicity),
- testable (capable of repeated verification), and
- unified (tendency to favor unified ideas).

Some additional characteristics of scientific knowledge include the concepts that science:

- is socially and culturally embedded,
- tends to be self-correcting as scientists critically review and analyze each other's research, and
- is best understood from a family-resemblance approach rather than as a hard line that separates science from other fields (Eflin, Glennan, and Reisch 1999; Smith and Scharmann 1999).

Students may find it easier to recognize the characteristics of science when they are shown how science is different from the field of technology. We observed that a common misconception students have is that there is no difference between scientists and engineers. Science is a field that tries to better understand and explain things in nature or to discover regular repeating patterns found throughout nature, while the goal of technology is to make products that address societal needs, rather than to explain why or how things work. Scientific knowledge is considered neither good nor bad (amoral); technology involves making moral decisions about how it will impact society, with often-unintended consequences.

Teaching the nature of science

Most students seem to have embedded misconceptions about the nature of science, revealed by comments such as, "Why would the book print something when they don't know for sure it is true?" or "My experiment proved my hypothesis was true." These comments suggest that students do not understand that much of science is about proposing logical explanations that fit known facts and observations; instead students tend to construct their own false ideas about what science is and how it works. Furthermore, students often retain their misconceptions year after year, even when they receive correct information in classes. Fortunately, science education literature includes many strategies for overcoming these misconceptions and teaching students the nature of science; we have identified three particularly effective methods.

First, researchers Abd-El-Khalik and Lederman (2000) found that one of the most effective methods for enhancing students' understanding of the nature of science was through the "explicit" approach, where the instructor provides a clear explanation of some aspect of the nature of science and does not assume students will discover this knowledge on their own. An effective link is to connect labs with explicit instructions from the teacher about why scientific methods and process skills are important. In a study conducted by Bell et al. (2003), it was determined that high school students did not understand the nature of science any better through laboratory experiences than just by using other inquiry methods, process skills, and implicit instruction. Lab activities are favorite methods of many teachers for helping students better understand how science works; nevertheless, unguided lab activities seemed to do little to help students understand these principles. It is especially important that teachers not confuse "discovery methods" with the need to provide clear explicit reasons for why labs need to include controls and variables, why conclusions are tentative, or why critical peer reviews of research are necessary. Better results may be obtained when labs are a combination of student inquiry and clear, explicit instruction by the teacher (Hackett 1998). Unless students are explicitly guided by their instructor to develop correct concepts, their own logic often leads them to reach naïve conclusions or outright misconceptions about the nature of science. Labs are good opportunities to provide specific information (explicit instruction) about the nature of science, but teachers can use other classroom times as well.

The second useful strategy we identified for teaching the nature of science is the use of historical stories (Carson 1997; Soloman et al. 1992). These researchers found that, properly used, stories promoted interest, helped build learning structures, and enhanced meaningful learning about both history and the nature of science.

A third strategy is persistence and frequency of exposure to the characteristics of the nature of science (Clough 1997; Reeves and Chessin 2003). Students tend not to fully understand many of the concepts about the nature of science the first time they are exposed to them;

however, if the instructor continues over a period of time to briefly present these concepts, using a variety of approaches, students are more likely to develop a realistic understanding of how science works.

Drawing on our knowledge and experiences in science education, teacher education, and as student-teacher supervisors, we concluded that the most promising approach to teaching the nature of science is one that incorporates all three of these effective strategies:

1. explicitly present the basic characteristics of the nature of science in a clear, specific manner;
2. read a historical narrative to illustrate these characteristics; and
3. follow up with frequent minilessons to reinforce the characteristics, including careful administration and monitoring of labs.

Finding effective historical narratives

Historical stories of scientists provide an excellent opportunity to help students see that science is indeed a human endeavor and demonstrate the interrelationships among science, technology, and society. A number of engaging historical accounts illustrate characteristics of the nature of science; stories brief enough to allow part or all to be read aloud in a class period are most effective. We observed that most students were quite interested in the life and work of the nuclear scientist, Lise Meitner (see photo, p. 31)—she defies the image of a stereotyped scientist, and her Jewish ancestry in the time of World War II provides a dramatic and fascinating portrayal of the human side of science during a time of persecution. We used selections from many resource books and from internet sources to compose a condensed but engaging story about Meitner's escape from Germany and her later discovery of nuclear fission (Figure 1).

The story of Lise Meitner leads students through the processes of how one of the most important scientific breakthroughs of this century occurred. Her role in nuclear research and her proposal of the nuclear-fission theory can be used to illustrate many of the characteristics of the nature of science (Figure 2). It also provides a meaningful introduction to the history of nuclear fission and the subsequent technologies of nuclear weapons, nuclear medicine, and nuclear energy.

FIGURE 1

Biography of Lise Meitner.

Lise Meitner (November 17, 1878–October 27, 1968) was born in Vienna, Austria to parents who valued and supported her education. She is known for her scientific achievements as well as for her struggle in a time of anti-Semitism and discrimination against women in science. Fittingly, her childhood heroines were Florence Nightingale and Marie Curie. She received her doctorate from the University of Vienna in 1907 and studied with Max Planck in Berlin, then collaborated with chemist Otto Hahn, during which time they discovered and explained the theory of nuclear fission. In 1937, Meitner's colleague and friend Niels Bohr helped her flee Nazi Germany for Sweden, where she spent the rest of her working life. In 1945, Otto Hahn won the Nobel Prize for Chemistry—Lise Meitner was overlooked for her contribution to their joint research that led to the discovery of uranium fission. She was honored as Woman of the Year by the National Women's Press Club (USA) in 1946, and received the Max Planck Medal of the German Physics Society in 1949. In 1966, she was awarded the U.S. Fermi Prize, along with scientists Otto Hahn and Fritz Strassman. Her nephew, physicist Otto Robert Frisch, created her headstone inscription, which reads "Lise Meitner: a physicist who never lost her humanity." Element 109 is named *Meitnerium* in her honor.

Connecting Lise Meitner's story to the nature of science

Meitner, continuing her research in Sweden after fleeing Nazi Germany, was seeking an explanation for why barium, with about half the mass of uranium, seemed to be appearing in the container of uranium when the uranium was bombarded with "slowed" neutrons. In 1938 the most common understanding of the nucleus of an atom was that of a hard, solid structure, which only allowed for small particles to be chipped off or absorbed by the nucleus. Based on the theory of a hard, solid nucleus and the knowledge that breaking an atom would require massive amounts of energy, the possibility of an atom splitting apart was routinely dismissed as improbable. In 1933, for example, Ernest Rutherford had reportedly stated that "Anyone who expects a source of power from the transformation of the atom is talking moonshine."

Working with the experimental data of her coworkers in Berlin, and with the collaboration of her physicist nephew, Meitner proposed that uranium atoms were indeed splitting. She used Neils Bohr's hypothesis that the nucleus might have liquidlike properties, as well as Einstein's famous $E = mc^2$, as part of her explanation *(unified characteristic)*. Her explanation was that as the nucleus absorbed an extra neutron it might become unstable and split; in the process, very small amounts of matter would change into huge amounts of energy. This was just as Einstein had predicted.

From the moment the scientific world heard of nuclear fission, other scientists analyzed, critiqued, and tested aspects of the theory multiple times over *(self-correcting characteristic)*. The contrast between the science of nuclear energy and the technologies it produced was readily apparent. As a scientist, Meitner never claimed

FIGURE 2

Characteristics of science in the story of Lise Meitner.

Common characteristics of science	How illustrated in story	Follow-up minilessons and assessments
Amoral	Meitner was focused on providing an explanation for why barium might have appeared in the uranium container. She was not trying to discover new uses for uranium.	Ask students to find articles that illustrate both science and technology and decide in which cases moral decisions must be made.
Creative	Meitner's explanation was derived from creatively thinking about what might be happening—not from making the same assumptions most other scientists had made.	Invite students to participate in a classroom discussion: Does a set of facts automatically lead all researchers to reach the same conclusions?
Tentative/ Developmental	Meitner didn't claim to have proven her proposed explanation for nuclear fission, but the facts fit her explanation better than the old theory.	Check lab reports for naïve conclusions that state or imply "I proved my hypothesis." Use explicit instruction to teach why hypotheses are not proven.
Parsimonious	Meitner's proposed explanation was stated as a simple concept that uranium atoms were splitting and in the process a small amount of mass was changing into a large amount of energy.	Conduct a DART activity: Students can use a text to look up nuclear reaction and chemical reaction, and state the differences in a way that a 10-year-old could understand.
Testable	Meitner believed the tests could be repeated and similar results would be obtained.	Employ teacher-directed explicit instruction: Explain why accurate measurement and elimination of extra variables are important when testing; can be assessed by means of a warm-up question for students. Use the failure to reproduce the results of the 1989 "cold fusion" experiment as possible example.
Unified	Meitner's explanation incorporated Bohr's liquid nucleus hypothesis and Einstein's $E=mc^2$ equation.	Conduct a DART activity: Read about Einstein's mass/energy equation in a text. Read about Bohr's contributions to atomic theory. Ask students to determine if either scientist knew about nuclear fission before 1938.
Socially and culturally embedded	Meitner's story revealed the prejudice against Jewish scientists that was promoted by Nazi Germany. Meitner's escape from Nazi Germany to Sweden allowed her the freedom to pursue her research and collaborate with different scientists in making further contributions to the knowledge base of science.	Encourage students to participate in a class discussion with no "right" answer: Why do you think Meitner never received the Nobel Prize for her discovery although her German partner did? How do you think the prejudice against Jewish scientists impacted Lise Meitner's work? How did Meitner's escape from Nazi Germany to Sweden affect her scientific research?
Self-correcting	Meitner's explanation was made available for other scientists to critique, analyze, and test further. In this way, errors and weaknesses could be exposed.	Invite students to write a paragraph about why scientists need to consider the views of all scientists even if they disagree with the researchers' conclusions.
Family resemblance	Lise Meitner, Neils Bohr, and Albert Einstein were all engaged in scientific research. The methods they used fit many of the characteristics of science, but at the same time, there were unique differences in their methods.	Ask students to tell about the methods Einstein used to do his research. For example, was Einstein a "real scientist"? What is a real scientist? Do all scientists conduct controlled laboratory experiments? Operate using the same methods?

to have proven her explanation *(tentative, developmental characteristic)*; nor did she propose how the information might be used in society *(amoral characteristic)*. She only knew her proposed explanation fit the data and observations and correlated mathematically. Lise Meitner's scientific understanding and creative vision enabled her to realize the potential of unexpected scientific findings *(creative characteristic)*. Her recognition of the importance of exploring the unforeseen led her to new discoveries—this creative insight is vital to the nature of science. Observations that may have been discounted can be crucial to building new explanations of how the natural world works. The story of Meitner provides a means by which these and other characteristics of the nature of science can be introduced, discussed, and reinforced.

Adding frequent minilessons

A variety of minilessons—including classroom discussions, warm-up questions, DART (directed activities relating to text) activities, finding related news articles, monitoring lab reports, and using explicit instructions—reinforce characteristics of the nature of science. They are easy to implement and do not require an unusual amount of time. Most of the mini-lessons are a type of assessment, which agrees with the *National Science Education Standard*'s recommendations of placing "less emphasis on testing students for factual information at the end of the unit or chapter" and "more emphasis on continuously assessing student understanding" (NRC 1996, p. 52). Figure 2 gives examples of how each of the targeted characteristics of science can be reinforced by a minilesson.

Integrating the nature of science into an existing curriculum

Lesson plans in any of the strands—life science, physical science, and Earth science—can be successfully and seamlessly integrated with the history and nature of science concepts. The different strategies described above require minimal preparation time and will not detract from the goals and objectives that teachers and their students must achieve throughout the academic year.

When students do not retain an understanding of the nature of science the first time it is presented, we suggest that teachers reinforce the basic characteristics of the nature of science with a historical narrative and then frequently and persistently use a variety of minilesson strategies to reinforce these characteristics. When students increase their understanding of the nature of science, they have gone a long way toward becoming scientifically literate citizens. ■

Carolyn Reeves (ctreeves@vista-express.com) *is an independent consultant of science education and lives in Oxford, Mississippi; Debby Chessin* (dchessin@olemiss.edu) *is an associate professor of curriculum and instruction and Martha Chambless* (mchamble@olemiss.edu) *is a professor emeritus of curriculum and instruction, both atThe University of Mississippi in University, Mississippi.*

On the web

Lise Meitner, Atomic Archive: *www.atomicarchive.com/Bios/Meitner.shtml*

Lise Meitner, San Diego Supercomputer Center: *www.sdsc.edu/ScienceWomen/meitner.html*

References

Abd-El-Khalick, F. and N.G. Lederman. 2000. The influence of science courses on students' views of nature of science. *Journal of Research in Science Education* 37: 1057–1095.

American Association for the Advancement of Science (AAAS). 1993. *Benchmarks for science literacy.* Washington, DC: AAAS.

Bell, R., L. Blair, B. Crawford, and N.G. Lederman. 2003. Just do it? Impact of a science apprenticeship program on high school students' understandings of the nature of science and scientific inquiry. *Journal of Research in Science Teaching* 37: 1057–1095.

Carson, R.N. 1997. Why science education alone is not enough. *Interchange* 28: 109–120.

Clough, M.P. 1997. Strategies and activities for initiating and maintaining pressure on students' naïve views concerning the nature of science. *Interchange* 28: 191–204.

Eflin, J.T., S. Glennan, and G. Reisch. 1999. The nature of science: A perspective from the philosophy of science. *Journal of Research in Science Teaching* 36 (1): 107–16.

Hackett, J. 1998. Inquiry: Both means and ends. *The Science Teacher* 65 (6): 34–37.

Lederman, N.G. 1992. Students' and teachers' conception of the nature of science: A review of the research. *Journal of Research in Science Teaching* 29(4): 331–359.

National Research Council (NRC). 1996. *National science education standards.* Washington, DC: National Academy Press.

Reeves, C.T., and D. Chessin. 2003. Did you really prove it? *Science Scope* 27(1): 23–26.

Rubba, P.A., and H.O. Anderson. 1978. Development of an instrument to assess secondary school students' understanding of the nature of scientific knowledge. *Science Education* 62(4): 449–458.

Smith, M.U., and L.C. Scharmann. 1999. Defining versus describingthe nature of science: A pragmatic analysis for classroom teachers and science educators. *Science Education* 83: 493–509.

Solomon, J., J. Duveen, L. Scot, and S. McCarthy. 1992. Teaching about the nature of science through history: Action research in the classroom. *Journal of Research in Science Teaching* 29(4): 409–421.

Editor's note

For more information on Lise Meitner, see "The Fission Vision," a chapter excerpt in this issue (p. 23) from Joy Hakim's book *The Story of Science: Einstein Adds a New Dimension.* Hakim's book is available online directly from NSTA at *www.nsta.org/store*.