Connecting Science and Technology

Exploring the Nature of Science using historical short stories

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Helping students understand the Nature of Science (NOS) is a long-standing goal of science education. One method is to provide students examples of science history in the form of short stories. This article modifies that approach, using historical case studies to address both the history of science and the history of technology, as well as the relationship between the two. This approach aligns with the emphasis on engineering and technology found in the *Next Generation Science Standards* (NGSS Lead States 2013; see box, p. 43).

Addressing misconceptions

Students rarely hold sophisticated views about the relationship between science and technology. In past years, for instance, a written NOS pretest I gave my physics students included the question: "What is the relationship between science and technology?" Their responses included:

- Science and technology are one and the same.
- Technologies are developed simply by applying science ideas.
- The goal of science is to create new technologies.

These misconceptions are worrisome. If students identify technology as the primary goal of science, they might conclude that any scientific research not directly pursuing technology is not worth doing—that is, students might come to devalue basic science research. Today's students are tomorrow's voting public, and the extent to which they value basic science can affect future governmental funding decisions.

I addressed such NOS misconceptions throughout the year in various ways. However, using historical case studies of technology proved especially effective for illustrating the science-technology relationship. Historical case studies involving technology can often reveal the creative and collaborative nature of scientific work; the durable, yet tentative nature of scientific ideas; and the importance of theories in interpreting data (Allchin, Andersen, and Nielsen 2014; Clough 2011). Contemporary examples can be useful, but historical cases are often more conceptually accessible to students and frequently can be related to the science content under study.

Targeting the science-technology relationship

The nature of the science-technology relationship is complex. Here is a short, noncomprehensive list of important ideas worth considering:

1. In many cases, scientific knowledge has guided technological development, but scientific knowledge is rarely sufficient for that development.
2. The knowledge base for technology is not always science. Important technologies were developed without scientific or theoretical knowledge.
3. Technological problems can spur scientific investigations.
4. Technologies are vital for doing scientific work; they allow for precise measurements as well as the observations of otherwise unobservable phenomena.
5. The goals of science and technology differ: In science, theoretical ideas are developed about the natural world, while technologies are created for practical reasons.
6. Scientists and technologists/engineers often work side by side, even though their goals, methods, and interests may differ.

This list illustrates the complexities in the science-technology relationship often absent from students' views. The list can provide points of departure for further NOS study (Clough 2007). For example, it's more effective to rephrase the first bullet point as a question: "In what ways do science ideas play a role in technological development?" I wanted students to wrestle with questions like this throughout the school year.

Creating an effective historical case study

Historical case studies provide an authentic view of science and technology in action (Clough 2011). Figure 1 briefly outlines several episodes in the history of technology that demonstrate important NOS ideas.

How might a science teacher use historical examples in the classroom? As research makes clear, teaching students history will not, by itself, improve students' understanding of NOS (Abd-El-Khalick and Lederman 2000; Lederman and Lederman 2014). Instead, the teacher must actively draw students' attention to the NOS ideas to help them reach accurate conclusions.

A common method is to have students read historical case studies. While historians have investigated the histories of many technological inventions, the work of crafting the case studies often falls on educators. To craft an effective historical case study on a scientific or technological idea, teachers should:

- stick to the historical details that most clearly illustrate the NOS ideas;
- embed 3–4 questions or statements (in bold) within the study that overtly draw students' attention to the targeted NOS ideas; and
- weave science content familiar to students into the story.

The first step requires the teacher to modify an existing historical text to make it grade-level appropriate while also highlighting the important NOS ideas. In the second step, the embedded questions draw students' attention to NOS ideas and directly confront student misunderstandings (Clough et al. 2010).

I provide a sample case study embedded with NOS questions online (see "On the web"). The case, about the history of glasses and optics, addresses the complex relationship between science and technology. It's geared toward 11th- to 12th-grade physics students. (Also see "On the web" for the Story Behind the Science, a set of college-level case studies with embedded questions focusing on NOS aspects other than the science-technology relationship.)

Appropriate texts are rarely included in typical curricular materials, and modifying an existing text is not always possible. Science curricula do, however, often provide the seeds for more in-depth study. I created the optics case study after reading a science textbook that mentioned curious facts about the invention of eyeglasses. I then explored several texts (Figure 1) specifically addressing the subject.

FIGURE 1

Historical cases that illustrate science-technology connections.

Technological example	Brief historical description	Science-technology themes	Supporting texts
Optical lenses	The inventor of the first eyeglasses is not known but was most likely an Italian glass craftsman. The inventor was probably well-versed in the technical knowledge of glass but was not likely aware of the scientific knowledge of optics. This was probably a good thing because the scientific knowledge at that time was inaccurate and indicated that correcting vision through lenses would be impossible! The tinkering of eyeglass and lens makers over the years eventually proved to be a boon for science, when a craftsman created the first telescope. Shortly thereafter, Galileo Galilei heard of the invention and produced his own, which enabled him to make a series of important astronomical discoveries.	Early eyeglass makers used technical, not scientific, knowledge for their work. Science knowledge can be useful but is not necessary for technological development. (ideas 1+2) The telescope has proven to be of great importance in science, illustrating technology's important role in studying the natural world. (idea 4)	Ilardi (2007); Johnson (2015); Macfarlane and Martin (2002)
Steam engine	Starting in the early 18th century, the steam engine became an increasingly important industrial technology. There was a technological problem, however, with describing and measuring an engine's efficiency. In the early 19th century, this problem motivated Sadi Carnot to develop a set of scientific ideas about ideal engines and thermodynamics. His theoretical ideas indicated what an ideally efficient engine might be like, and thus had implications for engine design. His abstract ideas, however, did not clearly point the way toward how to create such an ideal engine. More practical developments, such as James Watt's condenser in the 1760s, had much greater impacts on steam engine design.	Just as science can guide technology, this is a case in which technological problems spurred scientific development. (idea 3) Theoretical science ideas, such as Carnot's, can be useful for technological development, but the path from theory to practice is rarely clear. (idea 1) **(Table continued on next page.)**	Kroes (1995); Pacey (1974)

Technological example	Brief historical description	Science-technology themes	Supporting texts
Haber-Bosch process for ammonia	Throughout the 19th century, there were many unsuccessful attempts to mass-produce ammonia, an important industrial chemical. The technological problem was eventually solved by Fritz Haber and Carl Bosch in the early 20th century. The thermodynamic theory of Walter Nernst played a role in this breakthrough by clarifying the equilibrium reaction between nitrogen, hydrogen, and ammonia. It indicated that producing ammonia would work best under high pressure and high temperature. While effort was needed to produce equipment that could withstand such conditions, Nernst's laboratory demonstrated that it could, in theory, be done. Nernst's studies of ammonia were driven solely by his desire to test his theoretical ideas. But for Haber and Bosch, the goal was a new technological process.	Science ideas often guide technological work, but much work must still be done to translate them into practice. (idea 1) While science knowledge is useful for technology, it is not necessarily pursued with technology in mind. Nernst was not interested in mass-producing ammonia but in studying the natural world. (idea 5)	Kroes (1995)
Manhattan Project	The scientific principles underlying the atomic bomb had been developed for non-technological reasons. The presence of nuclear energy, for instance, was proposed to account for discrepancies found in the masses of atoms using a mass spectrograph. While some scientists saw the technological potential for nuclear energy, their main concern was accounting for natural phenomena. As nuclear science progressed, the technological potential became more apparent. Leo Szilard recognized the potential for a nuclear chain reaction that could produce a bomb. This possibility eventually led Szilard and other scientists, including Albert Einstein, to send a letter to Franklin D. Roosevelt that kicked off the Manhattan project. The Manhattan project was technological, not scientific: The fundamental science principles for producing an atomic bomb were already in place. Even so, scientists worked alongside engineers and technicians in this massive technological undertaking.	Scientific work indicated that a nuclear bomb was possible but could not indicate how one might be constructed. (idea 1) The scientific work of nuclear scientists was undertaken to learn about the natural world. While this knowledge led eventually to the atomic bomb, this was not their concern at the time. (idea 5) Large technological projects, such as the Manhattan Project, often involve scientists as well as engineers and technicians. (idea 6)	Hughes (2004); Jones (1985); Rhodes (1987)

Using case studies in the classroom

Using a historical reading in the classroom usually takes 45 minutes. To get the most out of the reading, students should be supported by strategies before, during, and after they read (Topping and McManus 2002). Before giving any NOS reading, ask students to respond to two or three questions about the science-technology relationship, such as:

- What are some ways that technology influences science?
- What are some ways that science has influenced technology?
- What makes scientific research different from technological research?

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013).

Standards
HS-PS4: Waves and their Applications in Technologies for Information Transfer

ETS2: Links Among Engineering, Technology, Science, and Society

Performance Expectation
The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities. The activities outlined in this article are just one step toward reaching the performance expectation listed below.

HS-PS4-5. Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.

Dimension	Name and *NGSS* code/citation	Specific connections to classroom activity
Science and Engineering Practice	**Asking Questions and Defining Problems** • Evaluate questions that challenge the premise(s) of an argument … or the suitability of a design.	The historical text helps students to understand the workings of glasses and telescopes. It also pushes students to consider the boundaries between science and non-science. Students ask questions about the natural and human-built worlds and distinguish a scientific question from a nonscientific one.
Disciplinary Core Idea	**PS4.C: Information Technologies and Instrumentation** • Multiple technologies based on the understanding of waves and their interactions with matter are part of everyday experiences in the modern world (e.g., medical imaging, communications, scanners) and in scientific research. They are essential tools for producing, transmitting, and capturing signals and for storing and interpreting the information contained in them. (HS-PS4-5)	The historical text describes the role of various types of telescopes in scientific research, all of which are based on an understanding of light as a wave. The text also makes reference to the color theory of Newton, which explains why prisms separate light into its constituent colors.
Crosscutting Concept	**Cause and Effect** • Systems can be designed to cause a desired effect. (HS-PS4-5) --- *Connections to Engineering, Technology, and Applications of Science* **Interdependence of Science, Engineering, and Technology** • Science and engineering complement each other in the cycle known as research and development. (HS-PS4-5)	Throughout the historical case study, students investigate technological design and are provided information and questions that address the science-technology relationship.

- Why might scientific ideas not lead directly to new technologies? What additional work might be needed?

Students can either record their responses individually or in groups of two or three. I ask students to share their responses on the whiteboard at the front of the room before the reading.

Next, the teacher distributes the historical case studies for students to read, either at home or during class. During their reading, students should write responses to the embedded questions. Using those responses as starting points, the teacher holds a classroom discussion about the targeted NOS ideas. This helps students better comprehend the reading and make deeper NOS connections.

For example, the reading describing the historical development of eyeglasses and telescopes asks: "While technologies are essential for scientific work, most technologies are created for reasons other than supporting scientific research. What were the likely goals of the inventors of eyeglasses and the telescope? How were the goals of Galileo different from those of inventors?" Students' responses to these questions typically include:

The teacher distributes historical case studies for students to read. Students' written responses to questions embedded in the reading are starting points for discussion.

- The inventors maybe wanted to be able to sell their inventions.
- Inventors maybe wanted to solve the problem of helping people to read, in the case of eyeglasses.
- In contrast, Galileo mostly wanted to learn more about stars and planets.

These are fine ideas but relate only to the case at hand. Follow-up questions during class discussions can require students to move beyond the reading:

- In general, what are some reasons why inventors do their work? What might motivate people who develop technologies? What about scientists?
- Science and technology are usually not so cleanly separated. What are some examples in which science and technology are hard to distinguish? (If students struggle with this, I often suggest the field of medical research and ask whether this should be called science or technology.)
- Why might we want to distinguish science and technology? What's the value of such a distinction?

Throughout discussions with students, historical case studies provide rich contexts for investigating these kinds of questions, strengthening student understandings of important NOS ideas. ■

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On the web

Glass and optics case study: *www.nsta.org/highschool/connections.aspx*

Story Behind the Science: *www.storybehindthescience.org*

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