General-education science courses should provide students with a foundation of knowledge about how the natural world works, a clear understanding of the nature of science and scientific inquiry, and an appreciation for the relationship between science and society. This chapter suggests a variety of approaches to engage students in their own learning and, with appropriate reflection, help them construct more scientific worldviews.

Reshaping Their Views: Science as Liberal Arts

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If we teach only the findings and products of science—no matter how useful and even inspiring they may be—without communicating its critical method, how can the average person possibly distinguish science from pseudoscience?

—Carl Sagan, 1996, p. 21

I enjoy teaching general-education science because I like to see the light bulbs go on. It is not that science majors do not have meaningful learning moments as well, but most have mastered the art of learning science and can comfortably package new information into an existing architecture of knowledge. Then, too, we have four years with which to influence their understanding of how the world works and how we know it. We have fewer opportunities to help the non-science major and we are often hampered at the start with student science deficiencies, misconceptions, and fears.

One of my goals is that students appreciate the value of learning science, and of this they usually report positive gains. Lately, though, I have been wondering if I have really changed the way they look at science and the world around them. Last year, as part of a collegewide assessment of critical thinking, I had students critique an unsupported scientific claim and an uncontrolled scientific experiment at the start and end of a course on scientific inquiry. For the most part, their answers were as uncritical and unsophisticated at the end of the course as at the start. Was I expecting too much in thinking that a course on how science works would make a difference?
Scientific literacy is about developing in our students the knowledge and habits of mind to be able to evaluate evidence and express well-informed and reasoned opinions on scientific issues of importance in today’s society (American Association for the Advancement of Science (AAAS), 1990; National Research Council, 1996). Most Americans have limited scientific knowledge and a poor understanding of how science works (National Science Board (NSB), 2004). In the general public, belief in pseudoscientific phenomena such as extrasensory perception and astrology is widespread, and there is evidence it has increased over the past decade (NSB, 2004).

Content-rich courses for science majors often overwhelm underprepared non-majors who fail to make meaningful connections between the material and their lives. Thematic, interdisciplinary courses that place science in the context of students’ lives help them make these connections and so, we hope, move them toward scientific literacy. But without an understanding of how we know what we know, what the strengths and limits of scientific inquiry are, and how to evaluate evidence critically, students build knowledge by adding interesting and meaningful information into a worldview that is still full of misunderstandings about the natural world around them. I recently had non-major students read a nicely designed research article testing the hypothesis that college students gain fifteen pounds during their freshman year (Graham and Jones, 2002). My students were able to read and correctly interpret the data, which showed an overall loss of weight for the small cohort followed in the study. When I asked my students if they thought the study failed to support the hypothesis, they all agreed, but then added that they still believed in the “Freshman 15” phenomenon because they had seen it for themselves.

We all seek patterns of order and meaning in the world around us. We develop our worldviews from our observations, both direct and indirect. When our observations do not mesh with our explanations, we can either ignore the observations or reexamine the explanations as we continue to build our worldviews. A scientific worldview incorporates skepticism, creativity, and analysis in pursuing puzzling observations, and although that worldview doesn’t guarantee correct interpretations, we believe that it provides us with the best way of learning about the natural world. In fact, the strongest scientific studies attempt to disprove our understandings, accepting that if they stand up to that level of scrutiny, they are more likely to be correct.

Scientists are motivated to understand how the world works. Approaches that lead them astray are ultimately counterproductive. An unscientific approach, in contrast, takes comfort in uncritically making new observations fit into favored explanations. I have a friend who believes that a certain over-the-counter medication, if taken at the first sign of cold symptoms, will prevent the development of the cold. If it does, his belief is reinforced. If it does not, he explains that he did not take it early enough. Every observation supports and strengthens his worldview, though it is most likely incorrect.
The worldviews that students bring into class are not necessarily challenged by even the most engaging science content. The course’s factual information is neatly stored (or not) with the rest of the student’s growing understanding of the way the world works. Students’ notions need to be challenged in a way that gets them uncomfortable with the knowledge and allows them to reshape their understandings of the world. Student understandings about the nature of science and scientific inquiry need to make them more critical purveyors of new information and more appreciative of the strengths and limits of science in society. Four kinds of experiences, with appropriate reflection, should help accomplish these goals:

- Student-centered, open-ended scientific investigations
- Experience with the primary scientific literature
- Familiarity with the people who do science, both good and bad, in historic and recent times
- Opportunities to work on meaningful, ill-structured problems

**Student-Centered, Open-Ended Scientific Investigations**

The college science laboratory is traditionally a place for students to gain first-hand experience with the material described in lecture, to practice using the tools of science, and to go through the steps of a scientific investigation. Many college labs are written in a cookbook fashion, with a certain outcome used as a measure of successful completion of the lab assignment. Writing structured scientific lab reports is a skill that is mastered through feedback and repetition. Students quickly learn what is expected of them. They not only value expected results over the unexpected, but they become frustrated when the lab work doesn’t progress as expected by the instructor. My colleagues sometimes complain that students do not read the lab instructions before coming to class and that students would get more out of lab if they did. While true, unless there are penalties for not doing so, there is not much incentive for the student. This is not “minds-on” work.

National reform efforts aimed at promoting scientific literacy argue for the importance of modeling the process of doing science through inquiry-focused science lab experiences (AAAS, 1990; National Research Council, 1996). The goal is not to make the student into a scientist, but by modeling the process, to create the experiences to ground an understanding of how science is done. In addition, if the student generates a question and the answer is not necessarily known, the motivation to answer the question drives the process. The focus, then, for both student and instructor, is in using good scientific reasoning and the appropriate use of scientific tools to answer the question. In addition, these experiences provide an opportunity for the development of scientific habits of mind, including creative expression, trust in observations, and the excitement of discovery.
The challenge at the college level is in designing authentic, student-centered research experiences using the equipment and time available. My experience using this approach with non-science majors is that the students do become engaged in the process and design reasonably good experiments given the time and resources available. However, I have found that the product of their investigation, usually a research report or poster presentation, to be a less than satisfying way to end this process. Student-generated questions are rarely answered in the time frame of the course, and the conclusions they reach often support the original hypothesis even when the data do not warrant it. The end of the investigation becomes focused on the final product, and the interest in answering the question as well as the lessons learned about the process of doing science become lost. The final product ends the student’s scientific investigation, but should not end the learning experience. Students need to critique each other’s experimental design, data analysis, assumptions, and conclusions and be given the opportunity to respond to such critiques in a continuous dialogue so they can come to terms with what they discovered and revisit the quality of their evidence and the role of scientific inquiry in answering their questions of how the world works.

Recent studies in science education have shown that simply engaging in the practice of scientific inquiry may not be sufficient to change the learner’s understandings about the nature of science; experience doing science grounded in active reflection of the learning process may be needed to effect change (Adb-El-Khalik and Lederman, 2000; Schwartz, Lederman, and Crawford, 2004 and references therein). In fact, one of the most intriguing aspects of these studies is the suggestion that scientists themselves may not be able to articulate reasonably contemporary views on the nature of science (Schwartz, Lederman, and Crawford, 2004). That is, successfully performing a scientific investigation may not depend on the scientist actively reflecting on the philosophical underpinnings of his or her work. However, science teachers, including university faculty, must have an explicit understanding of the nature of science, “the meaning of science, assumptions, values, conceptual inventions, method, consensus making and characteristics of the knowledge produced” (Schwartz, Lederman, and Crawford, 2004, p. 612) if that is a goal of their instruction and if they are to develop these understandings in their students.

Experience with the Primary Scientific Literature

Doing science and then reflecting on the learning process will move students toward scientific literacy. The reality, however, is that lab investigations are finite research experiences with limits to discovery imposed by the time and equipment constraints of a student course exercise. Students are motivated to solve an intriguing puzzle and generally enjoy the process, but they often do not see the relevance to their lives and to society. These experiences can be reinforced by having students read original research articles
that show how knowledge is moved forward in meaningful ways through this process of discovery.

Until recently, I did not have non-science students read original scientific research articles. I thought that without sufficient content knowledge and vocabulary, let alone statistical knowledge, the students simply would not get anything out of it. Instead I provided copies of research articles for students to look over to reinforce their basic understanding of the scientific process and to use as models of scientific writing for their lab reports. I first had non-science majors actually read and analyze a research article in a course that focused on scientific inquiry. I chose a short, readable paper in a peer-reviewed journal that tested a hypothesis I thought would interest the students. As an assignment, I asked specific questions about the hypothesis being tested, the design of the experiment, evidence presented in support of the hypothesis, and the general organization of the paper. I asked about the strengths and limitations of the study and finally, if they agreed with the conclusions of the study. The students were quite capable of reading and analyzing the paper but had trouble identifying its strengths and limitations. This was tied to their tendency to accept or reject the conclusions of the article based on their personal experience, not on the quality of the evidence. I realized that students do not understand variation and the nature of scientific data.

In *Benchmarks for Science Literacy* (AAAS, 1993), the authors say that in early elementary school, students need to understand that when they do an experiment in the same way, they will get the same results. By the end of elementary school, they need to know that this is not always the case. By the end of middle school, students should know that the “scientific challenge is to judge whether the differences are trivial or significant” and that it usually requires additional studies to decide (p. 7). In Graham and Jones’s Freshman 15 study I mentioned earlier, although the average subject lost weight, some freshmen lost up to fifteen pounds and some gained up to fifteen pounds. My non-science students did not know how to handle this variation. They supported their own impressions that the phenomenon was true by pointing out that some students in the study did in fact gain fifteen pounds. It took quite a bit of prodding for them to acknowledge that the average student in this study did not gain weight and that the fact that there was variation was both interesting and important and could lead to a better understanding of the phenomenon and to the next set of questions to study. It was fine to still believe in the Freshman 15 phenomenon, but these new beliefs needed to incorporate the results of this study and be treated as testable, new hypotheses.

The analysis of published articles offers a good opportunity to reflect on how science works, including the role of anecdote and creativity in developing hypotheses, the importance of testing hypotheses and designing good experiments, the strengths and limits of experimentation, the importance of trust in evidence, and the setbacks to solving problems we can face.
when we accept hypotheses without testing them. It also permits a better understanding of the process and power of peer review in science and provides another segue to a discussion of science as a social process.

A corollary to providing research articles to students is encouraging them to use the primary literature to help answer questions that matter to them. This is not an easy task for students, who frequently do not know how to use their libraries’ resources to find relevant scientific research studies and then have trouble wading through the jargon and sophisticated methodological and statistical procedures. At some point in their lives, though, when they need answers to health or other science-related questions that truly matter to them, we would like our former students to value scientific evidence over anecdote and pseudoscientific claims. They need to know how to search for answers to their questions directly or indirectly from the scientific literature.

**Familiarity with the People and Stories of Science**

Scientific discoveries occur within the context of the prevailing scientific worldview and social setting. What we know about the natural world and how we study it have changed dramatically over time, even the recent past. Our students come to us not understanding that factual knowledge of the world accumulates even as our explanations to account for it change. Students have difficulty understanding why scientists do not agree with each other and how prevailing scientific wisdom, for example on health recommendations or environmental issues, can change dramatically based on new evidence or new ways of looking at old evidence. Some students distrust science because they see scientific explanations as changeable and unreliable. Having students examine historical accounts of how we know what we know gives them an appreciation that scientific knowledge is provisional and builds on or replaces (and so, still builds on) progress made in the past. The goal is to understand that current scientific explanations, while they may be revised in the future, are still the best explanations we have for how the natural world works.

Scientists perform science and scientists make mistakes. Sigma Xi’s handbook, *Honor in Science* (1986), asks whether fraud and abuse are rare in science or whether the spectacular cases we see from time to time reflect just the tip of an iceberg. The system of peer review and the process of building on prior scientific discovery should expose bad science. A hallmark of pseudoscience is that it usually does not go through normal science channels, but is often presented directly to the public. Students enjoy learning about poorly designed experiments and about deliberate fraud and other abuses of science. Students need exposure to bad science, both deliberate and unintentional, to understand how easily we are fooled by what seems to be scientific information or experimentation. Students should be trained to ask, “How was that claim tested” each time they are exposed to new public announcements of scientific progress.
Opportunities to Work with Ill-Structured Problems

As we move our students toward better understandings of how science works, we need to provide opportunities for them to put their new scientific knowledge and understandings to work in an attempt to solve problems that are meaningful to them and important to society. We need to provide students with the opportunity to work with messy, ill-structured problems that are informed by, but not necessarily solved by, scientific information. Case studies provide an opportunity for students to ground scientific knowledge and develop scientific habits of mind, including critical thinking, problem solving, skepticism, and flexibility (Herreid, 2004; see also the National Center for Case Study Teaching in Science online at http://ublib.buffalo.edu/libraries/projects/cases/case.html). The Science Education for New Civic Engagements and Responsibilities project (SENCER) provides models and workshops for college educators as well as a national assessment project to see if the use of complex, unsolved public-science issues develops students’ science skills, interests, and civic engagement (Seymour, 2002). Both the National Center for Case Study Teaching in Science and SENCER help faculty develop their own case study modules; SENCER also offers support for using their modules in large lecture classes.

Local issues can provide opportunities for authentic research on messy real-world problems. I have had several classes of non-science students assess local biodiversity and use historical records to describe the very clear changes in species composition in our natural lands over the past thirty to two hundred years. The content of the course provides information about the general causes of species loss, but the clear explanations in the book become difficult to apply to the changes occurring locally. When students do field and library research and seek out experts within the community, they find that there are several different explanations offered, in many cases depending on the species, biological community, or expert consulted. Restoration ecology is a dynamic field in which experts often disagree about both methods and goals. In every class I have engaged in clearing nonnative plant species, there are always a few students who insist that the plants we are about to cut down have value and deserve to remain. These feelings are projections of one of many possible environmental values that students have likely never articulated. By exploring personal values, ecological knowledge, and environmental goals, students with different personal beliefs can come up with a consensus plan for restoration that respects and addresses competing value systems.

There are no clear answers to the problems of many of our pressing social issues that involve the application of scientific knowledge. As we use science to help us understand the consequences of our actions, we can better decide how we want to act. In the above example, students are reminded to ask, “How do you know” and “How could we test that” when they offer explanations for the changes they observe, and “What are the potential consequences of our actions” when they suggest changes in land-management
practices. The goal is to show students how important it is to have good scientific knowledge to make informed decisions, and how, ultimately, we may have to choose among competing social needs with consequences to each of our choices.

Science as Liberal Arts

What, then, do we want our students to know and be able to do as a result of their general-education science experience? We want them to know more science content—to know more about how the world works. We want them to have an intuitive understanding of how science works and the nature of science, and we want them to value and respect the evidence generated by scientific investigations. We want them to understand how science contributes to our ability to solve pressing social problems, and we want them both to trust in the process of peer review in science and to be critical of unsubstantiated claims.

Science literacy, then, is more than transmitting essential understandings about how the world works. In fact, we have to decide in what content to ground these other understandings because there is far too much science content knowledge to fit into the undergraduate experience even for the science major. We should be deliberate in our choice of science content and select content that both provides essential background for pressing issues in today’s world and also affords the opportunity to learn how we know what we know about science. We want to create those “aha” moments that show that our students connect with the knowledge, but that also show that they understand that science is a powerful way of making sense out of the natural world.

We do not do this by watering down science major courses. I have too often heard science faculty claim that general-education science courses are “baby science,” as if factual knowledge is the prize. We do have an obligation to our science majors to give them sufficient depth of science content knowledge and experience with the tools of scientific inquiry to prepare them successfully for careers in science. Beyond that, the goals should be similar for both groups of students. We have less opportunity to address these goals with our non-science majors, so we have to be intentional in our planning to meet them. One might argue that we should be more deliberate in our work with our science majors as well. Johnson and Pigliucci (2004) administered a survey to biology students in sophomore-level science courses and to business students in sophomore-level philosophy courses. The questions addressed factual science content, science process understandings, and pseudoscientific beliefs. The results showed that, while science students knew significantly more science content, they showed equally poor understandings of how science works and equally unskeptical responses to pseudoscientific beliefs. Perhaps these science students will develop better understandings of the nature of science over
their undergraduate career. It is likely that we need to build in explicit reflection about the nature of science and scientific inquiry with our science majors as well.

We might consider expanding the use of undergraduate science students in service learning as peer tutors and interpreters of science for non-science majors. The key is to ensure that the science students understand not only the content material, but also the goals of science education and the nature of science and scientific inquiry. The benefits would be to both sets of students. The science education literature is expansive on the attributes that characterize the nature of science and these understandings are at the heart of decades of reform efforts in pre-college science education (see Lederman, 1992). Most science faculty have no contact with this literature, and no matter what instructional strategies we adopt in our courses, it’s hard to imagine how we will change student understandings about the nature of science until we make these understandings an explicit priority in our undergraduate science instruction.

The good news is that the general public does support science and recognize its value even if they don’t understand it (NSB, 2004). However, as journalist Boyce Rensberger points out, “without a grasp of scientific ways of thinking, the average person cannot tell the difference between science based on real data and something that resembles science . . . but is based on uncontrolled experiments, anecdotal evidence, and passionate assertions. They like it all” (Rensberger, 2000). The role of science education is to fill in the gap. Universities have a triple role to play here. We influence the development of scientists, future educators, and, through our students’ general education, a large proportion of the general public. The prize in science education is in a deeper understanding of how we know what we know in science—in understanding about the nature of science and scientific inquiry. Disciplinary content grounds these understandings. Interdisciplinary knowledge and methodology prepare our students to contribute to the solution of problems that society faces.

Our general-education science program can meet these goals by providing opportunities for students to develop more scientific ways of thinking. We can encourage students to generate their own questions and help them design experiments to answer them. Students can read, evaluate, and discuss scientific research articles and connect them to problems that society is grappling with today. Students can see how society has influenced the course of science and how scientific discoveries have affected society. We can give students concrete examples of science done poorly (or not at all, though in the name of science) and the opportunity to use their knowledge to solve messy but meaningful problems. We can do all of this in a way that challenges students to confront their worldviews and actively reflect on their learning. We can plan our general-education program to create these experiences and move our students toward science literacy if we ourselves keep our eyes on the prize.
References


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