Promoting Science Literacy through an Interdisciplinary Approach

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Abstract: Recognition of the value of a scientifically literate citizenry has driven American science education reform since the 1950s. We have seen some improvement in the comprehension of science facts in the past 10-20 years, but far less improvement in Americans' understanding of the nature of science. College science courses are ideal venues for promoting science literacy. However, in an effort to condense a complicated subject into a single semester, the nature of science is often lost amidst the facts presented in a freshman survey course, often the entirety of a non-science major's experience in science. We argue that an interdisciplinary approach that integrates the sciences and the humanities can attract non-science majors, increasing these students' exposure to scientific concepts by relating them to students' existing interests and knowledge. This fosters science literacy by teaching students that science is a process of human inquiry with a distinct methodology, instead of simply a litany of facts. We recommend that a successful interdisciplinary course should present an engaging topic with which students can identify, incorporate opportunities for student research, and offer site visits to working laboratories.

Key words: science literacy, education reform, interdisciplinary teaching, chronobiology, history

INTRODUCTION

Recognition of the value of a scientifically literate citizenry has driven American science education reform and standards since the end of World War II. The relevance of science and technology as demonstrated in the Cold War was dramatically underscored in 1957 when the Soviet Union launched the world's first orbiting satellite, Sputnik 1, and it is no coincidence that the term "science literacy" first appeared in print the following year (DeBoer, 2000). However, the precise meaning of science literacy is not always clear. It is often loosely defined as a basic understanding of the nature of science. The ability to comprehend science journalism as represented in the *New York Times* is frequently cited as evidence of science literacy. Numerous authors have noted, however, that this definition is imprecise and elastic. Jon Miller (2004), Director of the International Center for the advancement of Science Literacy, argues that the *New York Times* standard is sufficient, while others have advocated for a spectrum of literacies that range from the average citizen to the scientist or policy expert (Bybee, 2010). In contrast, George DeBoer (2000), Deputy Director for Project 2061 of the American Association for the Advancement of Science, claims that the imprecision of the term is itself an asset. Because there are multiple paths to science literacy, argues DeBoer, the goal of educators should be to introduce students to the "world of science so they may pursue it throughout their lifetimes."

On the other hand, our inability to reach a consensus on the meaning of scientific literacy raises serious questions, for how do we measure and assess scientific literacy if we cannot readily define it? According to Miller (2004, 2010), approximately one in four of American adults currently possesses science literacy. This figure is based on surveys by University of Michigan researchers and the National Science Foundation (NSF) which assess factual knowledge (e.g., is an electron bigger or smaller than an atom) as well as a basic understanding of scientific inquiry represented by rudimentary probability questions and comparisons of experimental designs (NSF, 2010). American adults scored considerably higher on the fact-based questions than on questions intended to test their understanding of scientific inquiry. When asked to use their understanding of science to answer more conceptual questions, few Americans were able to do so. Since science and technology form the underpinning of our economy, medical system, communications, and entertainment, science literacy touches the lives of everyone. Society must be able to understand science in broad terms and provide constructive criticism and meaningful social oversight of the scientific and technical establishment.

For our purposes, we wanted our students to understand science as a process of inquiry which we defined to include the basic scientific method, how research questions are developed, the role of technology in scientific ideas and research, and an understanding of the implications of science in students' lives as citizens, consumers, and –hopefully–lifelong learners. We also sought to demystify how scientific knowledge is created or tested by exposing students to working laboratories and scientists.

Although college biology courses are an obvious venue for promoting science literacy, introductory courses are often taught as a deadening litany of facts that describe the natural world without significantly aiding students' understanding of science as a process of inquiry with a distinct methodology. Compounding this problem, most students complete their science courses as freshmen. Many math- and science-phobic students avoid additional coursework in biology or other sciences. This is especially unfortunate since the number of science courses taken in college is the strongest predictor of scientific literacy in American adults (Miller, 2004). On the other hand, the United States is fairly unique in requiring any science courses at all in college; nowhere else do colleges and universities require science courses for non-science majors (Miller, 2002). This may help to explain why the US ranks slightly above most Western European nations and Japan in science literacy (Scearce, 2007).

To attract a broader range of students, and to increase non-science majors' exposure to science, we recommend an interdisciplinary approach that integrates science and the humanities. To this end, we designed a sophomore-level seminar titled "Body Clocks: How Nature Tells Time" to investigate the biology, psychology, and history of chronobiology (e.g., biorhythms). In this paper we argue that an interdisciplinary approach that includes a humanities field is key to increasing non-science majors' involvement in science education and effectively enhancing students' understanding of the nature of science. We fostered science literacy by blending traditional lectures, class discussions, hands-on experiments, site visits to clinics and laboratories, and student research. Participatory learning, i.e., learning by doing, was an integral component of our course.

COURSE DESCRIPTION AND MECHANICS

Troy University offers an interdisciplinary course housed in the honors program in which two or three professors from different disciplines teach a seminar on a topic of their choosing. Our course, "Body Clocks," combined professors from biology, psychology, and history. Our central topic, chronobiology, was chosen as part of a National Science Foundation grant on the history of chronobiology. This history offers case studies which illuminate the nature of science, and by integrating history with biology and psychology, the interdisciplinary approach offered science and non-science students a way to investigate chronobiology as both a body of knowledge and as an intellectual endeavor–in other words, both the facts of chronobiology and the nature of science.

The semester was divided into four units: chronobiology as it relates to sleep, performance, health, and evolution. Throughout the semester we employed a variety of strategies to engage students with different learning styles, such as traditional lectures, class discussions, hands-on experiments, site visits to laboratories, demonstrations, and student research and presentations. Student assessment consisted of class participation, unit exams, and group research projects. As discussed below, the research projects were especially important because they involved students in all stages of scientific research. In the course of preparing for their projects, students completed the University's Institutional Review Board (IRB) certification and submitted their research proposals for formal IRB approval. Their experience with the IRB greatly enhanced their understanding of science as a process that often involves human experimentation, and it required students to consider the possible consequences of their research.

There are two approaches to teaching an interdisciplinary course involving two or more professors. In the first, the course is segmented by specialties–biology, psychology, and history in our case–to accommodate each professor's portion of the course with the individual fields covered serially. In the second, faculty integrate their material to create a cohesive course. We chose the second approach. Although initially we divided the responsibility for each class period into halves or thirds, we quickly learned that to accommodate spontaneous class discussions, it was better to have one professor lead on any given day. Each professor contributed several lectures for each unit, and we tried to provide bridges among our three fields as much as possible. Accordingly, each professor attended all lectures, and we frequently took advantage of questions or tangents that came up in class to interject our own expertise. We believe that a truly interdisciplinary approach requires that professors and students find the common ground in order to make the connections across disciplines. Our focus on science as a process held the topics together. Each unit considered fundamental questions about how scientists develop questions, test hypotheses, and draw conclusions. To do this effectively, good communication in the form of weekly faculty meetings was essential. Each week we discussed what had worked during the previous week, what did not, and how we would integrate our topics in the upcoming weeks.

Combining the biological and psychological approaches to chronobiology allowed us to provide students a way of understanding the topic as a body of knowledge that is highly relevant to their lives and interests. The history of chronobiology set this knowledge in a broader context. For example, in our first unit on the chronobiology of sleep, our biologist, Dr. Cohen, lectured on the biology of circadian rhythms and the neurological phases of sleep. Students learned the basic anatomy of the brain and the role of the pineal gland and regulatory hormones and chemicals in the sleep cycle. Then, psychology professor Dr. Hooten discussed the actions of common sleep aids and the physical and mental effects of sleep deprivation. Students were able to relate their personal experiences to this more technical information, leading to a lively class discussion of strategies for the "all-nighter" and how academic performance is affected under these conditions. Lastly, historian of science Dr. Ross discussed how scientists' understanding of sleep changed over the course of the 20th century. The dominant paradigm was that sleep was essentially a passive state: in the words of 19th century surgeon Robert Macnish, sleep was the "the intermediate state between wakefulness and death" (Macnish, 1834). This persisted more or less into the early 20th century. However, with the application of the electroencephalogram (EEG) on humans in the 1920s, researchers had the ability to peer into the brains of sleeping subjects for the first time. Scientists then challenged long held assumptions and asked new questions. With the discovery of the rapid eye movement (REM) phase of sleep in the 1950s, sleep was redefined as a dynamic process that included bursts of brain activity correlated with dreaming. By linking these diverse topics, students were able to understand the biology of sleep, apply what they had learned to their own lives, and form ideas about how technology can shape scientific research.

The hands-on learning activities in class and site visits to laboratories were valuable additions to the course. On the first day of class students estimated the passage of a minute under different conditions: eyes closed, eyes open, or one hand held in cold water. Working in small groups, students timed one another's estimates and then collated the data as a class. Such an activity not only helped break the ice, it also dramatically introduced the concepts of how we perceive time and rudimentary experimental design. As became our habit, after completing the time experiment, we immediately discussed ways to improve it and the statistical significance of the collected data. In addition to other in-class activities, students visited a sleep clinic, which demonstrated how data on sleep disorders were collected and evaluated. During the chronobiology of performance unit, we were able to visit the Army Aviation research center at Fort Rucker in Enterprise, Alabama which tests pilot performance under various conditions, including sleep deprivation.

These activities and excursions accomplished more than reinforcing the material covered in lectures and readings. For the non-science majors in particular, the site visits were invaluable introductions to working laboratories and real scientists. Students met researchers, asked questions, viewed equipment, saw real-world examples of how circadian rhythms are studied and why, and discussed how such research is funded. They were able to encounter science as an active process and laboratories as sites of knowledge production, rather than science as simply a body of knowledge disconnected from human actors and buried in textbooks. This aided in their understanding of the nature of science and, therefore, the acquisition of science literacy.

Student research comprised about 20% of their course work and further conveyed the concept of science as a dynamic process. Students were divided into three groups of six to seven students and assigned a general topic. With help from one of the professors, each group then developed its research questions, collected and analyzed their data, and presented their findings in-class and publicly at a student psychology conference held annually at Troy University.

Students were deeply involved at each stage of research. For example, one group focused on the factors that affect the quality of sleep. Students brainstormed to design a sleep journal that all the students and professors involved in the course would keep for three weeks. The class debated what data should be collected, how to maximize compliance, and what demographic information to collect. After completing IRB training and certification, the students also grappled with the ethical concerns of their experiments. How would they protect the privacy of participants while still gathering the information they felt was important to their study? For instance, is it appropriate to ask "do you normally sleep alone or with someone else?" Students thought this was important information to have, but considering that the participants might feel uncomfortable answering or might share a bed with a range of partners, they reworded the question to read "Do you normally sleep alone? (no pets, kids, bed partners, etc…)" After finalizing the questions and demographic data to be collected (and receiving IRB approval), students and professors kept track of their sleep for three weeks. The sleep experiment group worked with their professor to evaluate the data statistically and form their conclusions about which factors most affected quality of sleep.

Student research, such as the sleep experiment, involved students in all stages of scientific inquiry: formulating the research questions and hypotheses; developing questionnaires or other research tools; collecting and analyzing data; and presenting their results. This practical experience aided their understanding of the nature of science in ways that more typical science instruction does not. For the non-science majors, this experience was unique in their science education. Very few of the students had ever given a presentation at a conference, and most commented on the value of this experience in a survey at the end of the semester. We found that these research projects greatly enhanced students' understanding of the scientific method and the process by which scientific knowledge is generated, analyzed, and shared.

ASSESSMENT

We treated the interdisciplinary course as a pilot study. Twenty-one students enrolled in the course from five majors: biology, psychology, history, English, and American Sign Language interpreter training. Eight of the 21 were non-science majors, nine of 21 were women, and all but two of 21 were upper-classmen. Because this was a relatively small sample size, our analysis of the course was necessarily more qualitative than quantitative, but we believe the students fairly represented a range of majors and interests. As mentioned above, the interdisciplinary seminar is housed in the University's honors program, but all students are eligible to register for the course. Due to the novel interdisciplinary nature of the course, the students who registered tended to be more intellectually curious and engaged in the material than those in a required general education science course. This worked to our advantage in generating discussions and classroom participation, but it also demonstrated that by combining science with the humanities we were able to attract non-science majors to what was largely a science course. By this approach, science and non-science majors were exposed to disciplines they normally would not explore.

We assessed our success in increasing our students' science literacy through their unit exams, class discussions, research, and anonymous end-of-course surveys. The exams were written by all three professors and included multiple choice, fill in the blank, short answer, and essays. Student discussions were evaluated based on participation and the quality of student questions and comments. Shared experiences, such as the field trips, hands on class activities, or personal study habits, provided a spring board for class discussions that could lead to deeper conversations about the science of chronobiology. The research projects also provided shared experiences and a basis for student participation, as well as end products, papers and presentations, that the faculty assessed. Student surveys consisted of nine questions concerning the strongest/weakest features of the course, exams, and the value of the site visits, research projects, and presentations. Nineteen of the 21 students submitted these surveys. Using these various assessment tools, we found that we were most effective in the following three areas.

Demonstrating interdisciplinary connections

When asked what the strongest feature of the course was, about one third of the students cited the interdisciplinary nature of the course. Others commented on the "diversity" of information as the strongest feature or noted its "interdisciplinary nature" and "different perspectives." This was supported by the in-class discussions during which students were able to draw on information provided from different lectures and readings to examine chronobiology and by their essays on the unit exams. We used our separate fields to examine science as a process of inquiry, emphasizing *how* the science of chronobiology developed alongside the *facts* of chronobiology. That the students clearly recognized these connections is indicative of their development of science literacy.

Expanding students' knowledge of the scientific method

On the surveys several students self-identified as non-science majors and commented that they developed a new understanding of how the process of science worked or even a new interest in science. One student commented that the course explained "the scientific process" in a new way and another that he or she "learned how to conduct an experiment properly and follow through with it." Students also commented on the value of the research projects: "I appreciated that we were given simple ways to learn the experiment process," "it broadened my education and caused me to approach things in a different way, including many fields," "it allowed the class to experience what it is actually like to perform a research experiment and present it to our peers," and "invaluable." Based on the survey comments, class discussions, and the completed research projects, we believe that students successfully learned about the scientific method and the role of experiments in knowledge production.

This was supported by their exam and project grades. Of the top five grades in the course, three were biology majors, one was from the school of education, and the other was a history major. This was hardly a large enough pool from which to draw significant conclusions, but, as a pilot study, it indicated that our approach is worth pursuing.

Explaining the transmission of scientific knowledge

We required students to present their findings to the class and at the conference as described above. Developing students' presentation skills was a secondary goal of the course which fared better than we had anticipated. We expected this would help students understand how scientific knowledge is debated and shared. However, the conference proved to aid their professional development significantly. Each group planned their paper presentation together and selected two representatives to read their papers at the conference. We used the in-class presentations as rehearsals and the conference as the final product of their research. The quality of the final presentations was very high and far exceeded our expectations. The students also fielded questions at the conference, where they were required to explain their experimental designs, or to defend their conclusions.

On the end-of-semester survey we asked students about their reactions to the conference and they were nearly unanimous that it was very valuable, even exciting. Students remarked that "I enjoyed presenting, it gave me a sense of accomplishment" and "I am not a great public speaker so I was a little nervous; however I was very excited to have the opportunity to present our research in a professional environment." Some students noted that they believed the presentations would improve their résumés and that they were planning on attending future conferences. Again, this advanced our goal of promoting science literacy by demonstrating how scientific knowledge is created and then transmitted via public presentations and debates.

DISCUSSION

In order to attract both science and non-science majors to an interdisciplinary course, we believe it is essential to select a topic that will engage students broadly and on a personal level. Sleep deprivation (the all-nighter) or other personal experiences proved useful for generating discussion and engaging students from all backgrounds. This tended to short-circuit the science-phobia of non-majors by focusing on a topic with which they could identify. Inclusion of the humanities makes the material more accessible to non-science majors and broadens the education of science students as well. In our case, the history of science provided every student with an understanding of science as a human endeavor–a process of human inquiry.

Student research is invaluable if the goal is science literacy. Ideally, students should be involved in each step: developing research questions and methods, collecting and analyzing data, and presenting their conclusions. Through student research, non-science majors in particular gained a much better understanding of the nature of science. Science majors gained considerable experience formulating their own research questions (rather than the prescribed experiments typically found in class labs) and especially benefitted from presenting their findings in a more formal environment.

If possible, visits to sites where research is conducted are beneficial. Although field trips can be time-consuming, they offer most non-science majors their first experience with experimental science outside of the freshman biology lab. They were able to see the real life applications of the concepts they were learning in class and the relevance of chronobiology outside of their lectures and readings.

The benefits to students are worth the investment of time required for interdisciplinary courses and greatly outweigh the costs. In schools where this kind of labor-intensive team teaching may not be possible, science faculty may wish to consider adding lectures, readings, or field trips that demonstrate science as a process or that discuss science from the perspective of the humanities. History of science is an obvious choice, but science fiction, films, or art can also engage students and help them explore the nature of science and its implications for society. Classics such as *The Island of Dr. Moreau* or *Frankenstein* are two examples that come to mind and can lead to discussions about students' concerns in the 21st century: bird flu, genetically modified foods, or global warming. Interdisciplinary teaching serves as a powerful way to expand students' understanding of science and draw in those students who would otherwise avoid further science education.

After more than 50 years, the goal of increasing science literacy is still an important one, and one that has slowly been bearing fruit in America (Miller, 2004). In this interdisciplinary course, we were able to capitalize on the expertise and skills of three professors from different fields and effectively expose non-science majors to what was largely a science course. The inclusion of a humanities field was key to attracting these students and also benefitted science majors. Through lectures, active learning, research projects, and site visits, students learned about the nature of science, and developed a sense of how science is actually practiced. Students employed the basic scientific method, learned how scientific knowledge is generated and debated, and gained an understanding of the implications of science in their lives.

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