

5.3 Increasing Scientific Literacy in Undergraduate Education: A Case Study from “Frontiers of Science” at Columbia University

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General undergraduate education intends to broaden a student’s perspective, to advance alternative ways of thinking, and to develop empathy for other worldviews. While colleges and universities have ballooned with science courses in recent years, they do not often teach the scientific process nor cover the breadth of interesting, contemporary science content. There are many barriers that prevent undergraduates from learning science content and process. When science is not well integrated into a core education curriculum, students may choose not to take elective science courses because they view them as too difficult or worse, unnecessary for their future lives. The subsequent science illiteracy is a detriment to functioning in modern society. Columbia University has endeavored to repair this problem locally by creating a new required undergraduate course that makes science a chief component of a solid core curriculum; one that is collaborative and multi-disciplinary and offers students an opportunity to debate and discuss the philosophical, historical and methodological contexts of current research. This course also allows the faculty to create a forum for open discourse among the diverse student population where nearly eighty percent of students are humanities majors. Teaching science to all entering students in a context where the humanities have historically dominated is our laboratory for the development of a curriculum that shows how science can be made accessible to people of all backgrounds.

Bridging barriers between science and the humanities

General education seeks to develop students into well-rounded productive members of society, broadening student’s perspectives by exposing them to new ideas and a diversity of worldviews while giving them the tools to engage them. However, the physical sciences – important courses that teach critical thought and the process of experimentation – can

be quite peripheral or even absent from a general liberal arts education. Consequently, effective teaching of scientific ideas and the tools to understand them are often lacking in a general education. While colleges and universities are replete with elective science courses, students often do not take these courses because they feel they simply do not need them. Critical reports from the U.S. government such as *A Nation at Risk* [NCEE, 1983] and global reports such as the Trends in International Mathematics and Science Study [TIMSS; Gonzales 2004a,b] point out that American high school and college students severely lag behind their international counterparts when it comes to proficiency in mathematics and science [Gonzales, 2004; (NCEE), 1983]. This fact should be of concern not only to scientists, but to the nation as a whole. Insufficient science literacy makes students susceptible to deception and misunderstandings when presented with scientific findings or pseudoscientific data and creates a population unable to make critical decisions related to science and technology. In addition, when science is not well integrated into a general educated worldview, science can be easily misjudged as capable of taking the place of other modes of analysis; in particular, it can be asked to generate rules for deciding right from wrong or fact from fiction, which it cannot do [Pollack, 2001].

Identifying the barriers

There are many barriers preventing general education from bridging science and the humanities. The barriers include but are not limited to the enormous administrative changes required to create a novel core curriculum science course and recruitment of talented faculty to design and teach such courses. Here we consider some of the further barriers to incorporation of science education in undergraduate curricula and propose solutions from a new core curriculum course, *Frontiers of Science*, that we teach at Columbia University. There are at least three significant barriers to science literacy in the U.S. and abroad [Pollack, 2001]:

1. The cultural barrier of a general fear and antipathy to science in our society,
2. The political barrier of a misuse of general education, and
3. The academic barrier of resistance to change in the way science is taught.

First, the cultural obstruction to science entering general education properly has to do with the way science is generally received by the public. According to popular press in the many news magazines, films, and television shows, scientists are typically portrayed as white-coated practitioners of a pagan religion. They obey their own arcane rules, and then only to be first to uncover a mystery of the universe that might be better kept hidden [Pollack, 2001]. But since these discoveries can lead to new products with important value, the public cannot totally disregard their efforts. Even a more positive view of this predicament does not motivate the public or new students to pursue basic science literacy, let alone careers in science. Public interest in science from this perspective is reduced to a dealing with unknown and misunderstood purveyors of consumable, if mysterious, technology. Instead of understanding how science works and how scientists think, the public is left with a black box for science and with no real method for understanding its contents.

The second, political block to the introduction of science in general education is the misuse of general education to indoctrinate students instead of teaching them to think

critically. Such intellectual abuse sometimes begins with the notion that we are obliged to agree upon the high points of our culture and civilization, because together they define us as a nation or a culture. At other times it begins with the opposing wish to bring down the edifice of a national culture and replace it with the monuments of a set of approved subcultures. In either case, indoctrination does more harm than good and neither produces a well informed, scientifically literate public, nor a well educated graduate who has informed critically thinking ability, able to analytically evaluate information as it comes in from popular press, books, or people. Rather, poor science teaching misleads students to make them believe they understand science and scientific thinking when they have memorized a set of facts in a specialized content area.

Another obstacle to science in general education is neither political nor cultural. It is the purely academic resistance to general education as such in many science departments. The essential properties of the science component of a solid general education curriculum, we've found to be interdepartmental, taught by practitioners of science (Ph.D. scientists directly involved in research), and offer students an opportunity to debate and discuss the philosophical, historical and methodological contexts of current research.

By extension from our combined teaching experience we argue that the place of science in general education is to assure that science, and the ways scientists think, reason, and argue, become part of every student's exercise in learning to think for themselves [Pollack, 1981]. It is essential that teachers know how to expose a future lawyer or political figure, military officer or school teacher to a dose of the scientific worldview, to help protect them from errors analogous to ones we would have made had we not been exposed to a good core curriculum in the humanities and in science. These are the errors of believing that political decisions can be made in the absence of clear observation, that irrational certainties can be used as reliable indicators of proper action, or errors that involved mishandling of scientific knowledge. To avoid propagating these and other abuses of science, science teachers and their students must learn what science is, how it is practiced, and how it connects to the large questions central to general education [Pollack, 2001].

Richard Feynman, the late great physicist of Caltech, in a 1955 address to the National Academy of Sciences on the importance of the fundamental link between the practice of science and the purposes of general education, said:

It is our responsibility as scientists, knowing the great progress which comes from a satisfactory philosophy of ignorance, the great progress which is the fruit of freedom of thought, to proclaim the value of this freedom; to teach how doubt is not to be feared but welcomed and discussed; and to demand this freedom, as our duty to all coming generations. [Feynman, 1988:248]

Science provides one important and historically successful way for us to understand the world in which we live. The scientific method is a term used to describe how scientists ask questions and search for their answers by using observations, inferences and testing. And yet the majority of the public, even those who are well educated do not understand the nature of science and the scientific method [McComas, 1998; (NCEE), 1983; Gonzales, 2004; O'Sullivan, 2000; Lederman, 2005].

Science literacy in the United States

Science literacy is a necessary element of education in our modern science and technology driven society. It is crucial to teach science to all citizens, not only for those who actively and early choose careers in science. National Science Education Standards (NSES) exist to achieve this goal in U.S. education system, but these were designed and implemented for grades K-12 [(NRC), 1996]. Both the NSES and education research suggest the best way for students to learn science involves authentic inquiry based classroom activities. Few college science teachers are aware of these standards and the breadth of published science education research, which remains a significant problem. Undergraduate college science teaching is predominantly taught using a transmission-reception method better known as the “I teach, you listen” approach. This is unsuccessful for many reasons and yet is still the pedagogical method of choice for most college professors. Examples of successful discipline specific college science teaching show implementation of inquiry based activities increases student achievement, even in large classrooms [Wright, 2002].

Current test scores demonstrate the failure of the U.S. general education systems to develop science literacy among students. Results from the latest TIMSS (2003) assessment show that U.S. fourth graders were outperformed in mathematics by their peers in eleven participating countries, including four Asian countries (Chinese Taipei, Hong Kong SAR, Japan, and Singapore) and seven European countries (Belgium-Flemish, England, Hungary, Latvia, Lithuania, Netherlands, and the Russian Federation; Gonzales *et al.* 2004a). Similarly, U.S. eighth-graders were outperformed in mathematics by seven countries, including five Asian countries. Science results in the U.S. fared slightly better in 2003 with U.S. fourth-graders outperforming most countries except their peers in Chinese Taipei, Japan, and Singapore. However, fourth graders in 9 of the 15 countries that collected data in both 1995 and 2003 showed significant double-digit improvements in 2003 while U.S. scores declined. U.S. eighth-graders were further outperformed by their peers in seven countries in 2003. Overall, the TIMSS assessment shows U.S. 4th graders competing well enough in math and science, but by 8th grade they begin to fall behind, and additional results from high school students show the U.S. finishing dead last compared to other developed nations. These data are indeed worrisome since the difficulty of teaching science appears compounded by recent experimental data showing resistance to certain scientific ideas derive from assumptions and biases developed in early childhood and then persisting into adulthood [Bloom & Wiesberg, 2007].

Results such as those from TIMSS demonstrate the uphill battle educators face when attempting to solve the problem of science literacy among the general public. Other national assessment reports such as *A Nation at Risk*, underscore the need for drastic improvements in the way science is taught and learned in the United States (NCEE, 1983). According to the *National Science Education Standards*, scientific literacy is defined as “the knowledge and understanding of scientific concepts and processes required for personal decision-making, participation in civic and cultural affairs, and economic productivity” (NRC, 1996). This is a reasonable goal to expect of students, especially those that graduate from college. In reality, very few students who attend college choose science or engineering as a declared major [Tobias, 1992]. The Higher Education Research Institute at UCLA demonstrated a significant decline (from nearly 12% to under 6%) in the percentage of freshman choosing to enter and remain in math and science based-majors [Astin, 1993;

Seymour, 2002]. This means that the majority of students in college spend only a small fraction of their time in science classes, usually as non-majors. Educators are then faced with the problem of how to create a scientifically literate population when most students do not have adequate exposure to scientific thinking and concepts.

The problem of science literacy in general education

In order to create a scientifically literate society, one has to go beyond calls for knowledge of scientific concepts and methods of scientific experimentation. At the core of scientific literacy is the understanding of the tenets of scientific inquiry and the nature of science [(NRC), 1996; AAAS, 1993]. The “nature of science” refers to the values and underlying assumptions that are intrinsic to scientific knowledge, including the influences and limitations that result from science as a human endeavor (Lederman and Lederman 2005). “Scientific inquiry” refers to characteristics of the scientific enterprises and processes through which scientific knowledge is acquired, including the conventions and ethics involved in the development, acceptance and utility of scientific knowledge [Schwartz, 2004]. A scientifically literate individual should be able to articulate and critically utilize all three categories; the nature of science, scientific inquiry and traditional science content.

To address the issue of increasing scientific literacy in college student populations (as well as potentially increasing recruitment and retention in the science majors), undergraduate institutions are implementing multidisciplinary introductory science courses that advocate the interdisciplinary nature of all physical sciences and actively involve the students in the discovery process as a way of learning the nature of science [McComas, 1998; Lederman, 1992; Borgwald, 1994; Meichtry, 1993]. Implementation studies of undergraduate science curricular reform typically describe modification of an existing course that is often from a specific content area, is geared for a specific student population (i.e. majors or non-majors), and is developed by one to several primary instructors (see [Knight, 2005; Norton, 1997] for good examples). These studies provide proof that the use of inquiry-based pedagogical techniques such as student participation in large lectures and cooperative in-class problem solving show significantly higher student learning gains when compared to traditional lecture-based teaching.

Many studies suggest that the university must be open to the disposition of change and that science faculty need to be the agents of change in order to implement large-scale science curriculum reform for all students at the university level [McIntosh, 1996; Krockover, 2002; Krockover, 2001; Stockstod, 2001; (AAPT), 1996]. However, there is limited literature on professional development for college science faculty [Lederman, 1999; Krockover, 2001]. This may be due to limited interaction between college science faculty who design and teach new curricula and the science education researchers who report case studies of implementation of new curricula [Ziedler, 2002; Duggan-Haas, 2000]. In order to address this gap it is imperative to publish studies that bridge these two disciplines. Only with dialogue between faculty and education researchers, between science and the humanities, can progress be made on the failure of science literacy in the age of science and technology.

We hope to better understand the effects of inquiry-based pedagogy on teaching methodologies and teachers’ understanding and use of the nature of science and scientific

inquiry in the classroom [Crowther, 2005]. Understanding the implementation of curriculum as a political process and organizational change has the potential to create a dialogue among college science teachers. This dialogue is essential to the future education of American students in the sciences. Our contribution here will be to extend this dialogue between educators with discussion of a case study course, *Frontiers of Science*, at Columbia University. This case study is significant to both science faculty and administration of universities, as well as their educational research counterparts because it shows how faculty, without traditional pedagogical training, have been able to successfully develop inquiry-based lectures and activities for large classrooms while simultaneously learning new content and pedagogical methodologies.

Science education at Columbia University

Science education at Columbia University in New York has had a varied history. Columbia University was founded in 1754 as King's College by royal charter of King George II of England. It is the oldest institution of higher learning in the state of New York and the fifth oldest in the United States. It has three schools for undergraduate instruction, Columbia College, the Fu Foundation for Engineering, and the School of General Studies (for non-traditional students). Columbia College is a small college within the large private research institution. In 1917, just after the U.S. entered WWI, Columbia created the "core curriculum", a set of required courses for every graduate of Columbia College that introduces students to the great ideas of Western literature, art, music, and philosophy. For more than eighty years, the heart of the undergraduate experience at Columbia College has been its core curriculum and for many, it is a defining experience [Denby, 1993]. When we asked students during their first semester at Columbia why they chose Columbia over other schools, more than fifty percent responded, "because of the core curriculum". Yet in the eight decades since its adoption, the core curriculum has neglected the essential contribution of Western civilization: science.

Students spend a substantial part of their first years at Columbia College in small classes, reading and discussing primary works of literature, philosophy, history, science, and social and political theory, and studying fine arts and music. The core curriculum is designed to help improve each student's ability to engage in the kinds of analytic, discursive, and imaginative thinking that prove indispensable in both subsequent education and later life. Courses use discussion, debate, writing, and direct interaction between instructor and student to achieve this goal. The first attempt to teach science in the humanities dominated core curriculum began in 1939, on the even of the U.S. entering WWII, with a course called *Science A1*. The texts for it were all from the current literature of science, except for an introductory narrative, "Matter, Energy, and Radiation", written by a professor of physics, which was typed out by hand and mimeographed for distribution to the 500 men (Columbia College did not admit women until 1981) of Columbia College each fall. However, *Science A1* did not survive in the core curriculum. Only recently in Columbia's long history has there been a concerted effort to teach the nature of science, scientific inquiry and traditional science content to all students, ensuring that every graduate leaves the university scientifically literate. In 2003, Columbia science faculty created a new required core curriculum course, *Frontiers of Science*, designed to address science literacy

in a humanities focused educational institution. *Frontiers* was created in response to a need for incorporation of a common intellectual experience in the sciences for undergraduates, while also realizing that students should learn the analytical and quantitative tools that scientists use. It is clear that all students need the ability to critically examine scientific evidence if they are to make informed choices about pressing scientific, political, and societal issues – climate change, stem cell research, nuclear technology, transplants, the biology of the mind – and the problems that we cannot now imagine but will have to solve in the future [Kelley, 2006]. We treat *Frontiers* as a case study of specific methodologies for breaking down barriers to teaching science to non-scientists.

Frontiers was initially designed as a pilot in the core curriculum for incoming freshman in the Columbia College in the fall of 2003. As it was the first real change in the core curriculum in over eighty years, incoming freshman were asked to volunteer to take the course and 279 students responded. The course was subsequently approved for a five-year pilot and in the fall of 2004, all incoming freshman (over 1000 students per year) were required to take *Frontiers*. We recently completed our third full year teaching *Frontiers*.

Scientific habits of mind

In 1938, the American philosopher and educator John Dewey published a book entitled *Logic: The Theory of Inquiry* in which he coined the phrase “scientific habits of mind”. He characterized these habits as follows: (1) logical thinking (2) quantitative analysis (3) deductive reasoning (4) proper questioning (5) Reliance on sound evidence. These five scientific habits of mind make up the backbone of *Frontiers*. The nature of science was used as a foundation for development of *Frontiers* and is critical to understanding the design of the lectures and seminar activities. It is also at the heart of the faculty experience because it creates a common background where, regardless of content expertise, all faculty can exchange ideas and learn from one another by using their acquired scientific discipline or scientific habits of mind to communicate to one another.

Co-director of *Frontiers*, David Helfand, developed a web-based text, *Scientific Habits of Mind*, centered on Dewey’s theory. This text (accessible at <http://ccnmtl.columbia.edu/projects/mmt/frontiers>) provides a unifying theme across the physical and life science components of the course. The skills scientists use every day are explained in easy-to-read and often humorous language and include graph reading, estimation techniques, correlation and causation, proxies, experimental design, models, data analysis, sense of scale, descriptive statistics such as distributions, standard deviation and standard error, probability, feedbacks, and experimental bias. Students learn these skills by studying current research in fields such as conservation biology, neuroscience, global climate change, language evolution, astronomy, quantum mechanics, and evolutionary biology. While the specific frontiers of science (see the four example units below) provide the context for the course, the central emphasis of the course is on the scientific habits of mind. In short, *Frontiers* has two simple objectives. Firstly, it aims to disabuse students of the view that science is something that is simply memorized rather than a dynamic intellectual activity. Secondly, it aims to upgrade students’ basic quantitative and analytical reasoning skills. This is achieved by weaving scientific habits of mind through the course. Though the con-

tent changes from semester to semester depending on lecturer schedules and course content goals, the set of scientific habits outlined by Dewey remains invariant.

Course organization

Frontiers is designed so that professors give weekly lectures in their specific areas of content expertise. There are four senior lecturers per semester covering four distinct areas of content. Functionally, a *Frontiers* semester is organized into four units, two units of physical sciences and two of life sciences. Each unit is three weeks long and is framed by a central compelling question at the frontiers of science. For example, in the fall 2006 semester of *Frontiers* the four units consisted of:

Unit 1: Astronomy: What is our place in the Universe and is it unique?

Unit 2: Climate system: Are humans changing the Earth's climate?

Unit 3: Evolution: How has DNA based information lead to the emergence of life and thought?

Unit 4: Biodiversity: How will biodiversity loss affect life?

During a semester, each week begins with a lecture by a senior tenured faculty attended by half the first-year undergraduate class (> 500 students). This weekly lecture acts as a text for the course addressing the central question with data. A given semester may have a series of lectures by the chair of the Columbia astronomy department on cosmology, planet detection and scale in the universe; by a Nobel laureate in quantum physics on quantum mechanics and nanotechnology; by a National Medal of Science winner at Columbia's Lamont-Doherty Earth Observatory on the causes and consequences of climate change, the human signal in climate records, and carbon sequestration and climate solution technology; and by Columbia's Howard Hughes professor of biology lecturing on the structure and function of the brain, neuro-plasticity, and consciousness. The content of lectures comes from peer-reviewed journal articles as well as areas of personal primary research. Supporting the lecture are weekly readings from the primary literature (i.e. *Nature* and *Science*), popular science press and news media. The faculty also meet weekly post-lecture to discuss upcoming lectures, review reading materials, design activities for seminars, and coordinate the many aspects of this multifaceted course. It is often necessary to also meet during the summer period when the course is not held, sometimes bi-weekly, to develop new lectures for new content areas.

Being at the frontiers of science, the lecture material changes relatively frequently. Small changes are made to lectures from year to year, and the three-week units are rotated on a three-year time scale i.e. after three years of an astronomy unit, we may substitute a quantum mechanics unit. These changes however maintain the division of material into half physical sciences and half life sciences. The relationship between all content areas is the scientific habits of mind employed by scientists in each field. Lecturers make a point of emphasizing these overlapping scientific habits in each lecture so that lectures, regardless of content, map on to the required text, class exercises, readings, and assignments. All lectures are made available online as podcasts with both audio and visual files through a collaboration with Columbia's Center for New Media Teaching and Learning so that students as well as the general public have access to review past topics.

The heart of the course for the students is the weekly seminar. While the lectures provide the text for the course, the seminars provide an intimate environment (twenty students) to digest the lecture, the weekly readings, and to practice the scientific habits of mind. The seminars are taught by senior Professors and Columbia Science Fellows, postdoctoral researchers who are passionate about undergraduate education. Faculty traditionally teach one to two seminar sections per week and as do Columbia Science Fellows who are also primarily responsible for developing seminar materials.

The seminars are very diverse in their form. They generally begin with a recapping of the main points of the lecture through a discussion, then follow with the reinforcing of those ideas and the ideas in *Scientific Habits of Mind* through the use of activities and case studies. These discussion-oriented seminars are where the important transfer of the nature of science, scientific inquiry, and traditional science content to students occurs. Knowledge transfer is accomplished using action oriented hands-on learning activities from interrupted case studies, to actual group experiments, to debates, to question/answer discussion of readings and lecture content. The use of case studies has been a very successful tool to engage the students and to teach important scientific habits of mind. Further successful seminar activities include the critique of news media articles from the New York Times and BBC while contrasting these media articles with scientific literature.

Example course materials will be also available freely online in 2007 at *Frontiers of Science* Online (<http://www.fos-online.org>), a collaboration with Columbia's Digital Knowledge Ventures supported by the Howard Hughes Medical Institute. Material on the FoSO website will include podcasts, seminar activities and an overall users guide. We are also creating a discussion board for interested faculty to discuss their experience with the FoSO material and provide feedback, modifications and suggestions for alternative uses. The use of internal faculty discussion boards for the same purpose has been very successful at Columbia. We expect that the utility of the discussion boards will scale to the larger community addressed through FoSO. *Frontiers* faculty are also developing a series of process videos. For example, master teacher Deborah Mowshowitz teaches a seminar on how to teach a seminar.

The challenge of frontiers education

We acknowledge that the caution of generations of Columbia science faculty was well placed: teaching *Frontiers* is one of the largest educational challenges that our faculty has faced [Kelley, 2006]. One of the most unique characteristics of *Frontiers* is that every faculty member teaches every subject. Over the past two years we have taught stellar astronomy, planet detection methods, the biology of invasive species, biodiversity conservation, principles of evolution and DNA transmission, global climate change, human evolution, the anatomy and physiology of the brain and its relation to vision and language, the fundamental neural networks of the human body, quantum mechanics, Brownian motion, synaptic transmission and the influence of hormones, and more. While this can be disconcerting at first (to both faculty and students), the thrust is to demonstrate in the lectures, discussion, and class exercises, that mastering the *Scientific Habits of Mind* allows one to apply them to fields outside your expertise. With science literacy comes the ability to learn and understand new fields of inquiry. Most students respond positively to this approach,

and many say that they also learn by watching the way instructors approach a new scientific idea or question.

Scientific fields, and the scientists who work in them, are becoming increasingly specialized. This specialization is necessary because of the vast amount of knowledge and rapid pace of discoveries in each field. However, specialization does not require that a geologist, for example, completely lose touch with current research in astronomy, chemistry or biology. The results from teaching *Frontiers* shows that the positive benefits are not relegated to students alone, but rather faculty become a more integral part of the learning process, beyond simple communicators of knowledge, they are in turn learning as well.

Probably the largest challenge that faces faculty in *Frontiers* is dealing with the diversity of scientific literacy among first-year students, all of who are required to take the course. Our students range from nationally recognized science award winners to those with strong aversions to science for many reasons from religious, to political, to simple fear of mathematics. The challenge is to excite and engage across the whole spectrum of ability. Though this issue continues to be challenging, one novelty that has emerged is the creation of the optional Journal Club. The weekly Journal Club is designed to engage interested students at a deeper level not possible in seminars. The Journal Club covers one exciting discovery announced in a given frontier of science every week. These meetings are optional for students but are led by faculty in the course. The Journal Club gives students the opportunity to learn more about a given topic in the course, but probably more important is the chance to get to know other research scientists, to understand what they do, why they do it, and how. For example, one recent journal club was given by Professor Jaqueline vanGorkom on the evidence of the existence of dark matter provided by the collision of two galaxy clusters.

Like the scientific process, *Frontiers* continues to innovate and change as the data shows a more fruitful path to integrate *Frontiers* research into the undergraduate experience. *Frontiers* is not a history of science, philosophy of science, or a science and society course. Its concern is in exposing students to the science that is taking place in the laboratory today. In addition to exposing students to research techniques, methodologies, and experimental design, we have also begun a summer research program where students from a recent *Frontiers* course are placed in a Columbia research scientist's lab to learn the practice of doing science first hand. Similarly, to make sure students are exposed to as much actual science as possible, all instructors in *Frontiers* are active researchers. All instructors in the course have a Ph.D. in a relevant field of science. Scientific research, therefore, is built into the course from the beginning, not just through seminar activities, but by example through their instructors.

Theories of learning

The novel curriculum we use in *Frontiers* is very different than traditional science teaching because it aligns with nature of science and current supported science education reform movements. The Transmission Reception Method of teaching, though common in undergraduate education, is very unsuccessful for many reasons but is especially so in the science classroom [Lederman, 1999]. Conversely, situated learning theory (a theory of instruction) and the cognitive apprenticeship model (a model of learning based on situated cognition

theory) suggest skills may be acquired through authentic contexts and by communicating with peers and experts about those contexts [Duguid, 1989]. This is appropriate theory to use to describe the process of lecture development and seminar activities for the *Frontiers* course because the faculty used their own research data and expertise to develop context for the lectures that are given to the students. In cognitive apprenticeship students (in our case faculty) collaborate with one another under the direction of an expert instructor (also a faculty member) in both content and practice to work towards shared understanding of the topic being learned. This creates a culture of learning that allows faculty to process new concepts and information more thoroughly when multiple opinions, perspectives or beliefs must be accounted for across a group. It is also known that teachers learn from other teachers, both formally and informally through apprenticeship learning [Feiman-Nemser, 1993; Little, 1990; Lave, 1991]. *Frontiers* is a clear model of apprenticeship learning among faculty and between faculty and students.

The Dialogue: bringing science to humanities education

How can we make sure that general education includes the teaching of science such that students finish a given science course with a broad scientific literacy? The most direct way for outside granting agencies and governments to encourage science departments in universities and colleges to capture talented scientists for teaching in interdepartmental general education programs would be to pay them extra to do so. A precedent for such a subsidy exists. The National Science Foundation (NSF) and the Hughes Foundation help to cover the costs of faculty who are willing to take undergraduates into their laboratories for summer or term-time research. The NSF gives a grantee funding as a supplement to a regular research grant. What follows is a short list of additional recommendations for bridging the barriers to teaching science to non-scientists:

- As we've done with *Frontiers*, training grants for PhD programs and for postdoctoral fellowships in the sciences should include a supplementary stipend for teaching non-scientists. In the *Frontiers* program these are in the form of Columbia Science Post-doctoral Fellowships with required teaching in *Frontiers* as well as research.
- Practicing, funded lab scientists who are willing to put in the additional effort to teach non-science students ought to garner financial support for their research in exchange. This can be in the form of internal institutional grants or from outside funding agencies specifically targeted to fund such a program.
- It is important that research scientists who teach in general education courses also be able to apply to their funding agencies for additional graduate student support to offset time spent teaching non-scientists.
- Secondary school science teachers should be given the opportunity to spend a summer working in a research laboratory. At Columbia the Hughes Foundation supports such a program which has already sent dozens of high school science teachers back into the classroom with a new, strong, realistic commitment to teach science well with increased likelihood of successful translation of the nature of science to students.

- Similarly, courses designed to teach science to non-scientists, such as *Frontiers*, should assist interested students with placement in research labs so that any interest in science generated as a result of a successful course not be lost. In *Frontiers* we utilize the momentum from the course during fall and spring semesters to place top students in Columbia research labs during the following summer. *Frontiers* students are given the opportunity in the spring semester to apply for these competitive summer research positions with Columbia scientists to try out science in a lab experience for the first time. Preference is given to students not initially interested in science. This summer research program not only exposes students to actual laboratory science, but also encourages their interest with summer financial support and on-campus housing, making sure that we capitalize on the success of the course with the further motivation and hands-on experience important to inspire a future generation of scientists.
- As we've done with *Frontiers*, we recommend placing the undergraduate science learning experience in the students' first year so that they have opportunities to take advantage of the science education throughout the rest of their undergraduate careers. Similarly for potential undergraduate research, locating the research experience in the first or second year also works to honor the students as they participate in the research endeavor. Further, it provides them with confidence to continue with scientific research.
- It is critical to provide support for efforts to assess novel undergraduate experiences and courses and communicate those outcomes throughout the academic community. Such information is ubiquitous for K-12 education programs, but rare to nonexistent for undergraduate education. This is likely made more difficult because of lack of funding for assessment and dissemination. However, publication and dissemination of successful experiences is a critical component in transforming undergraduate education.

We have proposed a series of potential solutions to address the problem of science literacy taken from a case study course, *Frontiers of Science*. However, *Frontiers* is just the first step in changing the culture at Columbia University and throughout the U.S. in regard to teaching science and intrinsically valuing science education. One way *Frontiers* is transforming teaching at Columbia is that faculty who teach in *Frontiers* take what they learn from their time with the program and integrate the lessons into their own courses. Hence, it has become a faculty training ground. *Frontiers*, however, is not the only step that has been taken to transform the teaching culture at Columbia. Another simple and effective example is the creation of a brownbag lunch on teaching. These lunches serve as opportunities for faculty to meet to discuss teaching issues and to learn from each other's experience.

According to the course website, *Frontiers* “both introduces students to exciting ideas at the forefront of scientific research and develops the habits of mind characteristic of a scientific approach to the world”. While focusing on current frontiers of science students become involved in the debates and questions central to their instructors research and delve deeper into the science behind the headlines in popular press. In a uniquely diverse nation such as the U.S., we have an obligation to preserve a flat field for discourse among

the many ethnic and religious groups who have come together as American citizens over the centuries. Bringing greater dialogue between the sciences and the humanities will ultimately provide for a better general education of the public. General education in science is the one obvious but largely untested way to show the next generation of global citizens that science is in fact open to people of all backgrounds.

References

- AAPT (American Association of Physics Teachers) (1996) *Powerful Ideas in Physical Science*, Maryland, College Park.
- AAAS (American Association for the Advancement of Science) (1993) *Benchmarks for Scientific Literacy: A Project 2061 Report*, New York, Oxford University Press.
- ASTIN A. W. *et al.* (1993) *The American Freshman: National Norms for Fall 1993*, Higher Education Research Institute, Los Angeles, California.
- BLOOM P. & WEISBERG D.S. (2007) "Childhood Origins of Adult Resistance to Science", *Science* 316, 996-997.
- BORGWALD J. M., SCHREINER S. (1994) "Science and the Movies: The Good, the Bad, and the Ugly. *Journal of College Science Teaching*" 23, 367-71.
- BROWN J. S., COLLINS A. & DUGUID P. (1989) "Situated Cognition and the Culture of Learning", *Educational Researcher* 18, 32-42.
- CROWTHER D. T., LEDERMAN N.G. & LEDERMAN J.S. (2005) "Understanding the True Meaning of Nature of Science", *Science and Children* 43, 50-52.
- DENBY D. (1993) "Does Homer Have Legs?", *The New Yorker* 6, 52-69.
- DUGGAN-HASS D. *et al.* (2000) *Science and Science Education Collaboratives: Where We Are, How We Got There, and Where We Are Going*, Akron, Ohio, Annual Meeting of the Association for Education of Teachers in Science.
- FEIMAN-NEMSER S. & PARKER M. (1993) "Mentoring in Context: A comparison of two U.S. programs for beginning teachers", *International Journal of Educational Research* 19, 699-718.
- FEYNMAN R. P. (1988) *What Do You Care What Other People Think?: Further Adventures of a Curious Character*, Leighton, R. (Ed.), New York, W.W. Norton and Company, 240-248.
- GONZALES P., *et al.* (2004) "Highlights From the Trends in International Mathematics and Science Study (TIMSS) 2003", U.S. Department of Education, National Center for Education Statistics.
- KELLEY D. (2006) "Breaking the Pyramid: Putting Science in the Core", *Diversity Digest* 9, 2-3. Washington, DC, Association of American Colleges and Universities.
- KNIGHT J. K. & WOOD W. B. (2005) "Teaching More by Lecturing Less", *Cell Biology Education* 4, 298-310.
- KROCKOVER G. S. *et al.* (2001) "Action-based Research Teams: Collaborating to improve science instruction", *Journal of College Science Teaching* 30, 313-317.
- KROCKOVER G. S. *et al.* (2002) "Reforming and Assessing Undergraduate Science Instruction using Collaborative Action-Based Research Teams", *School Science and Mathematics* 102, 266-84.
- LAVE J. & WENGER E. (1991) "Situated learning: legitimate peripheral participation", New York, Cambridge University Press.
- LEDERMAN J. S. & LEDERMAN N. G. (2005) "Nature of Science Is", *Science and Children* 43, 53-54.
- LEDERMAN N. G. (1992) "Students' and Teachers' Conceptions of the Nature of Science: A Review of the Research", *Journal of Research in Science Teaching* 29, 331-59.
- LEDERMAN N. G. & NIESS M. L. (1999) "Training College Teachers", *School Science and Mathematics* 99, 413-17.
- LITTLE J. (1990) "The mentor phenomenon and the social organization of teaching", *Review of Research in Education* 16, 297-351.
- MCCOMAS W. F. (1998) "The nature of science in science education: rationales and strategies", Boston, Kluwer Academic Publishers.
- MCCOMAS W. F., ALMAZRO H., CLOUGH M. P. (1998) "The Nature of Science in Science Education: An Introduction", *Science and Education* 7, 511-32.
- MCINTOSH W. J. (1996) "The Dynamics of Change in College Science Teaching", *Journal of College Science Teaching* 26, 206-08.

- MEICHTRY Y. J. (1993) "The Impact of Science Curricula on Student Views about the Nature of Science", *Journal of Research in Science Teaching* 30, 429-43.
- NCEE (National Commission on Excellence in Education) (1983) *A Nation at Risk: The Imperative for Educational Reform, A Report to the Nation and the Secretary of Education*, United States Department of Education.
- NORTON C.G. *et al.* (1997) "Reinvigorating Introductory Biology: A Theme-based, Investigative Approach To Teaching Biology Majors", *Journal of College Science Teaching* 27, 121-26.
- NRC (National Research Council) (1996) *National Science Education Standards*, Washington, DC, National Academy Press.
- O'SULLIVAN C. Y. *et al.* (2000) *The Nation's Report Card: Science 2000*, U.S. Department of Education, Institute of Education Sciences, National Center for Education Statistics, Washington, D.C., U.S. Government Publishing Office.
- POLLACK R. (1981) "From Theory to Praxis: Columbia can and should include science in the general education curriculum", *Columbia College Today* 8, 21-24.
- POLLACK R. (2001) "Some Practical Suggestions for Teaching Science in the Liberal Arts. Presentation to the Conference on the Unity of Knowledge", *Annals of N.Y. Academy of Sciences* 935, 275.
- SCHWARTZ R. S., LEDERMAN N. G. & CRAWFORD B. A. (2004) "Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry", *Science Teacher Education* 88, 610-645.
- SEYMOUR E. (2002) "Tracking the Processes of Change in US Undergraduate Education in Science, Mathematics, Engineering, and Technology", *Science Education* 85, 79-105.
- STOCKSTOD E. (2001) "Reintroducing the intro course", *Science* 293, 1608-1610.
- TOBIAS S. (1992) *Revitalizing Undergraduate Science: Why Some Things Work and Most Don't. An Occasional Paper on Neglected Problems in Science Education*, Tucson, AZ, Research Corporation.
- WRIGHT R.B. & BOGGS J. (2002) "Learning Cell Biology as a Team: A Project-Based Approach to Upper-Division Cell Biology", *Cell Biology Education* 1, 145-153.
- ZIEDLER D.L. (2002) "Dancing with the maggots and saints: Visions for subject matter knowledge, and pedagogical content knowledge in science teacher education reform", *Journal of Science Teacher Education* 13, 27-42.