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The peer review process has long been the academy’s means of ensuring high quality in research, teaching, programs, accreditation, and other key areas. With this quarterly, AAC&U not only invokes this standard of quality but also embraces a more inclusive definition of the academic community. Every quarter, Peer Review brings together a broad range of contributors and readers—including anyone who wishes to participate in improving the quality of undergraduate education.

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Now, more than ever, the challenges of today’s world require greater facility with, and comfort in, the worlds of science, technology, and engineering. The time is right to do everything possible to improve students’ academic achievement in these areas. New forms of engaged learning promise to improve student achievement in the sciences and attract more students to major in these essential fields.

At the opening plenary for the 2005 AAC&U Annual Meeting, Lee S. Shulman, President of The Carnegie Foundation for the Advancement of Teaching, spoke on the need for classroom engagement, observing that student “invisibility breeds disinterest, [which] leads to zoning out.” And, of course, encouraging active learning is just one step toward true engagement. For the proverbial light bulb to come on, most students must find some connections with the subject to truly engage.

This light bulb allusion brings to mind a man who began his career as a mechanical artist and, once engaged, used his engagement to make key contributions to science and technology as one of the inventors of the light bulb. This innovator, who took a nontraditional path toward becoming a scientist, was Lewis Latimer, an African American draftsman who was hired in 1880 by U.S. Electrical Lighting to work for Hiram Maxim, Thomas Edison’s chief rival in the development of the incandescent light bulb. While Edison patented the first light bulb, Maxim endeavored to improve the product. Edison’s bulb only lasted a few days because the bamboo, paper, or thread filaments burned out so quickly. Although his background was in art, Latimer was encouraged by his employer to become engaged in the invention process. He enthusiastically took on the challenge and explored every aspect of electric light design. Through trial and error, Latimer devised a filament that was encased in a cardboard envelope, which allowed the bulb to burn longer. This improvement made the light source more efficient and affordable and, in concert with the improvements suggested by others, gave us the precursor to the lighting that we know today.

Latimer’s story provides but one example of the way that even traditionally underrepresented students can succeed in science and technology when encouraged and engaged. In today’s science classrooms, all students can become engaged through a host of new teaching methods discussed in this issue of Peer Review. Whether they choose to major in science or not, every student should leave college ready to make informed decisions in a world that presents its citizens with daily science and technology dilemmas.

The composition of the House of Representatives committee that oversees all of the major federal government science and technology agencies (such as NASA, NOAA, DOE, NSF, and EPA) provides an interesting test case for the significance of engaged science learning for all college students. Over half of the present committee members were government and political science majors; only a handful reference a science major or science-related career in their official biographies. Did they get enough engaged science learning in college to do their jobs well? As the committee “tackles some of today’s toughest issues and proposes ways in which research and development can solve some of our nation’s most pressing problems,” its members make recommendations on matters that have a profound effect on our present and future world. Their understanding of fundamental scientific principles and practices is crucial. Whether future members of this committee will have the skills and knowledge they will need depends on our success with engaged science learning today.

As the new Peer Review editor, I am pleased that my first major project has been editing this issue on Science and Engaged Learning. I came to AAC&U after fifteen years of working with many dedicated K-16 teachers while managing journals produced for science educators. Starting my editorship with a journal on this theme seems a natural place for me to begin—sharing key strategies to engage the hearts and minds of science students. —SHELLEY JOHNSON CAREY
Engaged Learning: Are We All on the Same Page?

By Stephen Bowen, senior fellow, Association of American Colleges and Universities, and senior administrator (on leave), Bucknell University

Engagement is increasingly cited as a distinguishing characteristic of the best learning in American higher education today. Vision statements, strategic plans, learning outcomes, and agendas of national reform movements strive to create engaged learning and engaged learners. Despite this emerging emphasis, an explicit consensus about what we actually mean by engagement or why it is important is lacking. Is engagement an end in itself, or a means to other ends? Is engagement as important as other characteristics of a good education such as intentionality, balanced breadth and depth, complexity, multidisciplinarity, integration, and contextual awareness? And, while we are asking questions, perhaps we should begin by asking—

Engagement with what?

Educators think of engagement in four related but different ways. The most fundamental is student engagement with the learning process: just getting students actively involved. The second is student engagement with the object of study. Here the emphasis is on stimulation of students’ leaning by direct experience of something new. Another is student engagement with contexts of the subject of study. This gives emphasis to the importance of context as it may affect and be affected by the students’ primary subject. When social and civic contexts are considered, this inevitably raises ethical issues. Finally, there is student engagement with the human condition, especially in its social, cultural, and civic dimensions. According to this way of thinking, the human condition is the ultimate subject of study to which individual subjects and disciplines should be understood as subordinate. Each of these ways of thinking about engagement has an interesting history, relationship to the others, and relationship to the goals of liberal education.

Student engagement with the learning process is a concern as old as teaching itself. The disengaged student daydreaming in the back row has always been a challenge for his or her teacher. To successfully compete with all the other forces impinging on the consciousness of children, adolescents, and young adults, teachers must gain a larger measure of influence than they are normally granted by developmental processes established through some four million years of human evolution. Passion, sensitivity, creativity, and persistence have long been important to teachers’ success in getting students to pay attention to the learning process and become engaged learners. Today, teachers make extensive use of pedagogies designed to compel students’ active engagement. Grounded in advances in our understanding of how students learn, these pedagogies of engagement include frequent short-term feedback, writing across the curriculum, cooperative learning, and learning communities. The National Survey of Student Engagement, which assesses the extent to which these pedagogies are used on various campuses, has become one de facto operational definition of engagement.

Although just paying attention to the learning process may be enough engagement for students to acquire knowledge and skills, teachers who value
liberal learning* are not likely to consider this sufficient. They will be interested in transformative learning—learning in which students grow in response to what they have learned. Here, engagement is more intense and more personal. As students attempt to reconcile what they learn with what they previously believed, they demonstrate growth in understanding, values, and commitment typical of mature cognitive development (Perry 1981). The idea that intense personal engagement in the learning process is important to the development of values has achieved cultural currency. For example, in a recent interview in Newsweek magazine, Wynton Marsalis emphasized the importance of intense personal engagement for development of aesthetic values in music when he stated, “The entire country has been in decline in terms of the arts. . . . Short of being given rituals of initiation into adulthood—and art courses that demand engagement and development of your taste—there is nothing to do but descend.” In some cases, new learning challenges old values and results in new values. In other cases, new learning deepens already-held values. As the learner’s values are examined and refined, broader experience and growing confidence enable growing commitment. Teachers who want their students to engage with transformative learning processes confront an additional challenge. Beyond the challenge of just getting students to pay attention, teachers find that students resist transformation—it necessarily threatens the student’s current identity and worldview. Socrates found that his students resisted conclusions to which he led them when those conclusions differed from their already-held beliefs. Teachers have the same experience today. A survey of students at an elite liberal arts college revealed that the majority did not want to engage in a discussion unless they had firmly held views on the specific issues and felt well prepared to defend them (Trosset 1998). Students felt that the purpose of discussion was not so much to learn as it was to defend one’s already established views and convince others of them.

The emphasis in engaging the object of study is different. Here students are asked to directly examine, characterize, analyze, and evaluate the object of study so they may build knowledge in response to it. This approach has always been fundamental to learning in the sciences. Laboratory and field exercises and experiments produce direct engagement with the object of study and, in using the methods of empiricism, students learn just as scientists learn. For objects of study typically not examined in the sciences, the same concept is readily extended in close examination (close reading) and rigorous analysis of history, literature, cultural anthropology, etc. Engaging the object of study assumes engaging the learning process, whether or not learning is transformational. Learning environments typical of institutions committed to liberal learning give priority to providing both opportunities and motivation for students to engage the objects of their study.

Engagement with the contexts in which the subject of study is situated adds two dimensions to learning. One is breadth. Complementary disciplinary perspectives on a single subject produce a more holistic and thus realistic analysis. This is as true in science disciplines as it

* For an elaboration of the goals of a contemporary liberal education, see Greater Expectations: A New Vision for Learning as a Nation Goes to College (AAC&U 2002).
is in any other disciplines. Let’s say we were learning about the population dynamics of fish in a lake. We would understand this better if, in addition to the population’s birth and death rates, we knew the effects of pollution and weather cycles on fish populations and the effect of the local human economy and culture on fishing pressure. If eating fish is taboo, it would have a different effect than if fish meals are customary for all major holidays. Such an approach to learning helps to remedy the alienation that some learners feel in response to analytical reductionism. Although research that concentrates on ever smaller fractions of nature intentionally isolated from context in controlled experiments achieves levels of precision that are truly impressive, its relevance to our understanding of the wider world is often an unresolved question. Alfred North Whitehead, one of the great scientific/mathematical analysts of the twentieth century, argued that despite their power, abstract systems of scientific knowledge should not be mistaken for the concrete reality of nature (Whitehead 1967). Many learners, students and their teachers alike, find exchanging some precision for the realistic complexity that comes with engaging context to be a gratifying trade. When engagement with contexts includes social and civic contexts, the subject’s ethical dimension is revealed. This was not always considered to be appropriate. There was a moment in the history of the analytical ideal when cold objectivity and disengagement from social context was considered essential to the purity of science. The dysfunctional consequences of this view were immortalized in a 1965 song by satirist Tom Lehrer who, in a parody of rocket scientist Wernher von Braun, wrote: “‘Once zey are up, who cares where zey come down? / Zat’s not my department’ says Wernher von Braun.” Of all the aspects of a subject that may be intellectually stimulating from a detached, abstract perspective, some will hold greater social and civic significance than others. Thus, awareness of the subject’s social and civic situation can guide analysis and interpretation, and can shape priorities for future learning. Understanding context also helps to anticipate the consequences of our acting on knowledge. Among programs that train students for the professions of engineering, law, nursing, and medicine, among others, the importance of engaging the social and civic contexts of professional practice has become an article of faith.

There are some teachers for whom engagement with the human condition, especially in its social, cultural, and civic dimensions, is the most worthy, compelling, and legitimate approach to learning. We are, after all, humans ourselves, and we should be most capable of, and in need of, learning about humanity. If engagement with the object of study reflects the analytical ideal that dominated intellectual developments through the 1960s, then engagement with the human condition reflects the “cultural turn” of the 1970s that continues to the present (Bender 1997). Beginning with the view that all knowledge is socially constructed and highly influenced by the social context of its construction, it would follow that understanding necessarily depends on knowledge of the sociocultural context. Although scientists have found this perspective less essential than others, it unquestionably has been the dominant view shaping intellectual developments in the humanities and social sciences in the last thirty years. Rightly, then, it is a powerful influence in shaping goals for learning in these disciplines. The cultural turn is so pervasive that it may be equally influential in institutions dedicated to liberal education and in others, although the priority given to student-teacher interaction in liberal education may favor more thorough development of this perspective on engagement.

Many of these concepts of engagement cover ground similar to that covered...
by initiatives in higher education known by other names:

- Engagement with the learning process is similar to *active learning*.
- Engagement with the object of study is similar to *experiential learning*.
- Engagement with contexts generally is similar to *multidisciplinary learning*.
- Engagement with social and civic contexts is similar to *service learning*.

Perhaps the most important contribution of engagement is the focus it brings to the learner’s personal relationship to learning. This emphasis is consistent with our recent appreciation that knowledge is more constructed than received, and that the primary agent of learning is the student. Thus, teaching and learning are different, and a focus on the learner is essential to the improvement of teaching. From this perspective, we can understand engagement as both the means to an end and an end in itself. Teachers strive to produce engagement as a means to learning. If a student is engaged in any of the ways discussed above, then learning of some kind would seem assured.

Among the essential characteristics of an undergraduate education that prepares graduates for life in the twenty-first century, engagement is surely as important as any other. Intentionality, balanced breadth and depth, complexity, multidisciplinarity, integration, contextual awareness, and engagement are at once characteristics of the learning process and characteristics of what is learned. Although none of these acts independently, engagement would seem a prerequisite for the others. Considered within the full range of meanings discussed above, engaged learners are those who complement and interpret what they learn from others with direct knowledge based on personal experience, who develop appropriately complex understandings situated in relevant contexts, and who recognize learning’s moral implications and consequences. Inasmuch as it contributes to such signature outcomes of a contemporary liberal education, the emphasis on engagement has served learners well and will continue to be important for the foreseeable future in science and many other disciplines.

**References**


In addition to its annual meeting, AAC&U offers a series of working conferences and institutes each year. Additional information about the upcoming meetings listed below is available online at www.aacu.org/meetings.

**Network for Academic Renewal Meetings**

**April 14-16, 2005**

**Pedagogies of Engagement:** Deepening Learning In and Across the Disciplines

Greater Washington, DC

October 20-22, 2005

**Integrative Learning:**

Creating Opportunities to Connect

Denver, Colorado

**November 10-12, 2005**

**The Civic Engagement Imperative:**

Student Learning and the Public Good

Providence, Rhode Island

**Summer Institutes**

**May 20-25, 2005**

**The Institute on General Education**

Newport, Rhode Island

**June 22-26, 2005**

**The Greater Expectations Institute**

Burlington, Vermont
Engaged and Engaging Science: A Component of a Good Liberal Education

By Judith A. Ramaley, visiting senior scientist at the National Academy of Science and professor of Biomedical Sciences; fellow of the Margaret Chase Smith Center for Public Policy at the University of Maine; and president-elect, Winona State University; and Rosemary R. Haggett, director, Division of Undergraduate Education, National Science Foundation

We live in a period of rapid and complex socio-economic change. The forces driving this change are reshaping the educational landscape in ways that we are only beginning to understand. Many recent reports and books, including the 2002 report from the Association of American Colleges and Universities (AAC&U), Greater Expectations: A New Vision for Learning as a Nation Goes to College, have explored the implications of these changes and have identified growing gaps between the intentions and assumptions of faculty, the actual experiences of students, and the demands of the workplace. The lack of clarity of purpose in undergraduate education is the outcome of a complex set of changes in higher education that need serious attention. Among these crucial elements are (a) changes in faculty career pathways as well as faculty roles and responsibilities; (b) changes in the demographics of the student body and patterns of enrollment and participation in postsecondary education; and (c) escalating demands created by changes in both the campus experience and the workplace that are driven by widespread use of technology and the emergence of high-technology industries and applications.

In light of these developments, we must reconsider who teaches, what they teach, who learns, how they learn, and what our graduates will do with what they learn. According to U.S. Department of Education statistics, nearly 60 percent of all students attend more than one institution as undergraduates, and they do so in a variety of ways over often prolonged periods of time. Increasingly, faculty must think about shared responsibility for improving the coherence and purposefulness of their expectations for their students, not only by working with colleagues in other disciplines at their own institution, but also by working across institutional boundaries. Faculty and administrators are beginning to address a set of common questions that must be answered in order for the academic community to articulate the broad outlines of a common set of goals for undergraduate science education. We must work together to attract a diverse and talented group of students to the study of science while, at the same time, ensuring that all of our students enjoy a high-quality education in which science plays a meaningful role.

What Does It Mean to Be Educated?
The basic skills required for successful entry into the workforce and reasonable professional progress are more demanding than they were even a decade ago. In The New Division of Labor: How Computers are Creating the Next Job Market, Frank Levy and Richard Murnane (2004) argue that computers are better at deriving solutions than people when the problems can be described in a rules-based logic that provides a procedure for any imaginable contingency.
What a rules-based system cannot do, however, is deal with new problems that come up, problems unanticipated by the program of rules. Most importantly, computers cannot capture the remarkable store of how-to or tacit knowledge that we all use daily but would have a lot of trouble articulating. As Levy and Murnane (2004) put it: “In the absence of predictability, the number of contingencies explodes as does the knowledge required to deal with them. The required rules are very hard to write.” One wonders, in fact, if the rules underlying creativity and innovation can be written at all.

Increasingly, capacities such as cognitive flexibility, creativity, knowledge transfers, and adaptability are becoming the new basic skills of an educated generation. The Business-Higher Education Forum, in its recent report *Building a Nation of Learners* (2003), explores the “widening ‘skills gap’ between traditional training and the skills actually needed in today’s jobs and those of tomorrow” and urges higher education to adopt new approaches to learning that offer more engaging and relevant content and experiences targeted to individual learning styles and needs. In an earlier report, the Forum identified nine key attributes necessary for today’s workplace: leadership, teamwork, problem solving, time management, self-management, adaptability, analytical thinking, global consciousness, and strong communication skills (listening, speaking, reading, and writing). Those attributes echo the vision sketched out in AAC&U’s *Greater Expectations* (2002). In combination, the message is clear. It matters not only what we know but also how we know it, how we use what we know, how we work with others who have different expertise than our own, and how well we respond to unexpected challenges that we encounter.

**What Role Does Science Play in the Undergraduate Curriculum?**

Taught in an engaging and engaged way, science offers a wonderful vehicle for introducing and practicing the habits of mind, inclinations, and skills required in today’s society. Science as a subject matter, and as a way of making sense of the world, is important in its own right.

Science as a subject matter, and as a way of making sense of the world, is important in its own right. Fostering a deeper understanding of how science is done, how knowledge is tested and advanced, and what science can and cannot offer us must be critical goals of a quality education in the twenty-first century. In addition, the study of science, when it is engaging and interactive, is an appropriate and necessary component of a good liberal education because it offers an opportunity to practice the advanced skills so important in today’s world—leadership, teamwork, problem solving, analytical thinking, and communication. We have also learned that changes that make science more attractive to nonmajors may also encourage students who might not otherwise have considered a career in science or engineering to major in a scientific field. So, from the perspective of the science faculty, improving science education is both a matter of service to the education of all students and self-serving, in the best sense of that term.

**How Should Science Be Taught in the Twenty-first Century?**

As in other aspects of the curriculum, the teaching of science and its place in the requirements for graduation have settled into familiar forms and patterns that must be reexamined and updated in order to bring the content in line with how science is advancing today and what we have learned about how people learn. They also need to be rethought in light of what we know about how studying science can contribute to the development of the qualities of an educated person and what we are learning about why students choose to pursue science or decline to do so. The award portfolio within the Division of Undergraduate Education in the Directorate of Education and Human Resources at the National Science Foundation (NSF) offers an excellent vantage point for examining the core assumptions that have shaped the science curriculum in the past and that are being held up and
carefully examined in today’s scholarship of teaching and learning.

*Enrollment in a class is not a proxy for real student engagement.* Faculty cannot assume that their students are either engaged with the material or even really interested in it just because they have signed up for a class and are paying tuition. Faculty must engage students in the learning process and recognize the diversity of people in their courses who differ in interests, backgrounds, cultural experiences, expectations about their own education, and commitment to pursuing an education.

*Science does not always have to be introduced in a hierarchical and sequential way.* There is evidence that the careful step-by-step building of a base of knowledge that usually determines the sequence of science courses can leave students cold. Recent experiments with the use of interesting problems, questions, and case studies as “hooks” to intrigue and engage students suggest that it is important to build a case for why something is worth knowing before plowing into it. (For examples of investigative case-based learning see Waterman and Stanley 2000).

*The nature of scientific inquiry is changing and will allow for changes in the way science is taught and learned.* The nature of science and the ways in which scientific knowledge is advanced are changing in significant ways. As this happens, our approach to the curriculum must change to reflect the new capacities made possible by advances in science as well as by the capabilities in new instrumentation and infrastructure. A particularly interesting analysis of these issues can be found in BIO 2010 (National Research Council 2002). In the future, according to this report, the scientific disciplines will be shaped by the following assertions.

New educational tools will have profound effects on the nature of education and will enable new approaches to involving students in research, new strategies for introducing contemporary scientific ideas and theories into the curriculum, and new ways of thinking about public outreach and engagement. The revolution in science will affect our goals for learning, how we approach the curriculum, and how we shape the student experience, resulting in:

- the convergence of the disciplines, with a blurring of disciplinary boundaries and the emergence of integrative fields;
- the growth of multidisciplinary interest in the science of learning and the availability of deeper understandings of how people learn;
- the capacity to model dynamic systems.

Taken together, these advances will allow those involved in education to model,
investigate, and manipulate “continuous, dynamic, simultaneous, organic, interactive, conditional, heterogeneous, irregular, nonlinear, deep, multiple processes” that are difficult to understand and that are increasingly characteristic of world affairs. The result will be a revolution in science education.

*There are many reasons to offer laboratory experiences, but there is very little agreement on what we seek to accomplish through hands-on work and how best to design experiences that lead to the outcomes we do identify.* We need to learn more about when a lecture is a good idea and when it is not. We also need to examine when and how to mix didactic material and delivery with more significant student engagement with original material or data or simulations. What do students learn from each of these experiences? Do we want our students to learn how to do research, what research is all about, or to develop skills of inquiry? Do we simply want to illustrate important concepts and ideas that are hard to get across in a classroom? Do we want to stir the imagination and show students that science can help them to achieve their own goals? Are we simply hoping that getting students physically involved in doing something will also get them mentally involved?

*There are a number of ways to engage students that do not involve actual laboratory experiences.* Active learning can take many forms. It appears clear that creating active participation in lectures through peer instruction (Mazur 1997; Fagan, Couch, and Mazur 2002), studio-style classes where students work in groups (Beichner, forthcoming), and other active learning strategies can help students develop the habits of mind that are characteristic of scientists. Slowly, science faculty are becoming aware of advances in science teaching and learning and are becoming interested in applying the same standards of scholarship to their role as educators that they do to their own research programs. As new approaches are being developed to record, document, and make publicly available the results of the scholarship of teaching and learning, the ideas and commitments will spread more rapidly.

Much of this work is now accessible on the Web (Handelsman et al. 2004). Now that the work is being made public, assessed and critiqued by colleagues, and built upon to create a shared body of experience and knowledge, this kind of scholarship can establish its legitimacy.

*Linking the study of science to societal problems can prove especially helpful in attracting and retaining women and students of color. Engagement models also can facilitate the accommodation to different interests and learning preferences.* Although there is no agreement on whether there really are different learning styles, most people have come to believe that there are multiple ways to stimulate the interests of students in a particular subject and that, as John Dewey argued, linking learning to life is an especially good way to engage most students. By the time students reach the postsecondary level, their interests and learning predictions are becoming clear. There may be, in fact, good reasons why some students seek to avoid the study of science or mathematics. They may, for example, find the objective model underlying scientific inquiry to be too “cold” and analytical. Or they may simply be intimidated by the mathematical reasoning required to understand many scientific concepts. We need to understand those reasons and provide ways for students who do not wish to think like prototypical scientists to bring their own interests and capacities to the study of science.

Is science more approachable and interesting for many students if it is blended with the study of other subjects or approached through the study of large societal questions that have a strong scientific component? Should scientific content be introduced through service-learning programs that link science to concrete community issues? Evidence suggests that women and underrepresented groups are more successful in learning settings that emphasize hands-on, contextual, and cooperative learning (Goodman Research Group 2002). Is a community setting a better laboratory for some students than a virtual laboratory in cyberspace or a campus science lab? What do students learn in these different settings? What about these environments fosters both motivation and learning?

### A Growing Interest in the Science of Teaching and Learning

From the perspective of the NSF, we can see a pattern of growing interest in teaching and learning, both within individual scientific disciplines and across disciplines, that extends back over a decade.
This work is spreading through a combination of collaboration among investigators, incentives at the federal level to improve the quality of undergraduate education, commitments at campus levels to rethink faculty roles and responsibilities, and investments in campus infrastructure. Building from new knowledge about how people learn (Bransford et al. 2000), faculty are gaining a better understanding of what happens in their classrooms and how to adapt the curriculum both to meet contemporary needs and to respond to changes in the students they serve. One result has been the use of new approaches such as Just-in-Time Teaching (JITT) (Novak et al. 1999, Patterson and Novak 2003) and Peer-Led Team Learning (Gosser et al. 2001).

Although we are far from seeing the widespread adoption of a scholarly approach to the challenges of enhancing undergraduate education, this work is beginning to expand more quickly and we have hopes that soon it will be expected that full-time faculty carry responsibility for designing the curriculum, engaging students, and ensuring successful learning outcomes. This work may take several forms. For some, it will be an ongoing professional commitment and may be the core of their scholarly contributions. Some disciplines such as physics have already taken serious steps to incorporate research on learning in the discipline as legitimate work for tenured faculty. For instance, there are a growing number of doctoral programs in physics education. Other faculty members may simply open up their courses to study by colleagues. Some may shift their interests from “basic research” to aspects of educational scholarship in the course of their careers. At the very least, faculty are becoming more aware of and informed by discipline-based educational research.

What is most encouraging about the growing interest in the scholarship of learning and teaching is that the work has become steadily more rigorous and convincing. The evidence is mounting that faculty at institutions of all types are growing more serious about their educational responsibilities and that they are approaching this work in a scholarly manner similar to the way they pursue an idea in their own disciplines.

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Advances in science and technology have fundamentally transformed our lives. We live longer, travel faster and farther, and have ready access to more information, resources, goods, and services than previous generations would have thought possible. However, as new technologies emerge, new challenges arise. Computers have become pervasive—greatly facilitating communication and expanding access to information but also providing new opportunities for theft, loss of privacy, and corporate fraud. Rapid advances in biotechnology promise to alleviate disease and enhance quality of life, but at the same time, they raise difficult ethical and economic questions. New models for agriculture have made more foods more widely available, yet also create concerns regarding biodiversity, genetic modification, and rural sustainability. As an array of technologies drives economic growth, the resulting demand for energy threatens both the natural environment and our national security.

Virtually every important public concern involves scientific or technical issues. However, the extent to which advances in science and technology will meet fundamental needs of communities is uncertain. Science and technology education has too rarely involved social issues, and technological development has been driven more by opportunity and possibility than by human need. Future leaders in science and technology must better understand the societal contexts in which science and technology takes place. In an increasingly technological world, human progress and quality of life will increasingly depend on science and technology education that is informed by social and civic awareness and directed toward the needs of communities.

Calls for Civic Engagement in Science and Technology Education

With colleges and universities under public pressure to demonstrate their value, a consensus is emerging that preparation for civic responsibility must be part of general education, and also of education in the disciplines and professions. AAC&U president Carol Geary Schneider (2003) has described civic engagement as “an organizing principle in today’s discussions of higher learning,” noting that in a knowledge-intensive society, we bear responsibility to “give our students practice in considering the implications of . . . different courses of action that may be based on their knowledge.” Once considered the responsibility of primary and secondary schools, education for civic engagement is increasingly seen as an imperative for higher education.

Today’s students will face the responsibilities of freedom in a complex, dynamic world that does not organize itself neatly into academic disciplines; they need preparation for participation in democracy as well as in the economy. To be responsible actors and
effective leaders in their professions and communities, students of science and technology, in particular, must learn to make connections between academic learning, professional practice, and important public questions, so that as professionals and practitioners they can pose their own meaningful questions and seek sustainable, appropriate solutions.

The engineering profession recently articulated a clear call for change in how its future practitioners and leaders are prepared. ABET, the Accreditation Board for Engineering and Technology (2004), has established new criteria that differ substantially from previous standards, requiring demonstration that students attain “an understanding of professional and ethical responsibility,” “a knowledge of contemporary issues,” and “the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.” Recently the National Academy of Engineering (2004) took a similar public stance, issuing a report entitled The Engineer of 2020 that calls for “engineers who are broadly educated, who see themselves as global citizens, who can be leaders in business and public service, and who are ethically grounded.” Driven by professional imperatives, and also by emerging institutional desires to educate students for democracy, engineering and technology programs are seeking new strategies for helping students to understand their work in broader contexts.

Curricular change is never easily achieved, and science and technology present particular challenges for reform. Faculty members whose careers are based on specific expertise can understandably find it difficult to see connections between calls for educational reform and their own work, which is often more focused on the creation of new knowledge than on bringing that knowledge to practice. To help students think and work in context, we must venture outside our own disciplinary boxes—a cultural challenge with implications not only for the curriculum, but also for how the faculty is trained, supported, and rewarded.

Promising Practices for Civic Engagement in Science and Technology Education

Effective models for making science and technology education more context-based can address both national calls for change and institutional priorities. As colleges and universities explore ways to become better citizens of their own localities, any resulting collaborations between institutions and their communities present an opportunity that can merge well with the goals of preparing students for citizenship. The increasing presence of community service activity on U.S. campuses is laudable, but often this activity takes the form of volunteerism that is unconnected to the curriculum. Community service often lacks the type of engagement defined by as “the production of new knowledge and the placement of that knowledge in the service of moral aims” (Burns 2001). Student engagement also requires the presence of unscripted problems in the curriculum that challenge students to produce new knowledge and weigh the costs and benefits of multiple solutions.

Engagement, and the active learning role it implies for students, can result from a variety of pedagogical strategies that involve students in open-ended inquiry, especially in response to the needs of communities. The Association of American Colleges and Universities (Schneider 2001) has identified especially promising practices for promoting engaged, active learning that can help prepare students for social and civic responsibility, including collaborative inquiry, experiential learning, service learning, project-based learning, and integrative learning. These strategies typify an emerging vision for undergraduate education. Although not new, they are increasingly featured in programs of study in more consistent and intentional ways, in orientations, seminars, and learning communities; core courses in general education and the majors; and in capstone experiences. These
engaging pedagogies help students bring together theory and practice to make connections between knowledge and real-world problems. In science and technology curricula, it is especially effective to tie these strategies to the disciplines, so that students begin to see connections between their fields of study and social contexts.

A Case Study in Civic Engagement for Science and Technology

Worcester Polytechnic Institute (WPI) has featured pedagogies of engagement since the early 1970s, when the university adopted a project-based approach to undergraduate education. All WPI students, about 90 percent of whom major in engineering or science, must complete a series of three projects that collectively help them to make connections between theory and practice and to better understand themselves and their world. In the junior year, students complete the Interactive Qualifying Project (IQP), an interdisciplinary project that helps students understand how science and technology affect society, and also how science and technology can be more responsive to social issues and human needs.

The IQP is equivalent in credit to three courses, but it is not organized as a course. Students work in small multidisciplinary teams—typically two to four students—under the guidance of faculty advisors, addressing problems that are usually posed by an external sponsor. After being given an open-ended problem description, student teams establish project goals, conduct background research, and collaborate with advisors and sponsors to pursue the project goals. Typically, field work is involved to gather information relevant to the project, and social science methods inform the analysis. In addition to whatever system, product, or recommendations are appropriate to the problem at hand, students develop a formal written report, and also orally present the results of their work to faculty advisors and the sponsoring agency.

The educational goals of the IQP include critical and contextual thinking, written and oral communication skills, teamwork and professional skills, and in particular an understanding of the interrelationships between scientific and technological advance, societal structures, and human need. Student teams and faculty advisors come together from different disciplines—engineering, natural sciences, management, social sciences, and the humanities—bringing different perspectives to bear on problems that may or may not be related to their areas of specialization. The majority of projects are completed in close collaboration with governmental agencies, nongovernmental agencies, and not-for-profit organizations.

WPI has been able to sustain this interdisciplinary project because it is central to the curriculum, an academic requirement for all undergraduates. Faculty members from every academic department participate, often in multidisciplinary teams. WPI’s Interdisciplinary and Global Studies Division serves as a campus-wide resource, supporting student preparation and faculty development for the IQP as well as providing administrative oversight to a worldwide network of project centers at which IQPs are conducted. Exploiting WPI’s unique academic calendar, the project center model allows students to complete their IQP by working full time during one seven-week term,

These engaging pedagogies help students bring together theory and practice to make connections between knowledge and real-world problems.

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Engagement in Democracy and Local Issues
The Worcester Community Project Center (WCPC) was established to provide opportunities for engagement in local affairs and to make focused contributions to WPI’s home city. Like most midsized U.S. cities, Worcester, Massachusetts, faces challenges involving economic development, environmental quality, planning and infrastructure, cultural preservation, and enhancement of quality of life for a diverse population. Projects at the WCPC involve student teams with municipal government offices, local schools, community development organizations, and grassroots efforts to promote a better future for the city. Examples of these projects include the following:

- Urban Planning: Working with the Office of the Mayor, student teams developed plans for a business park and an arts district, as well as for brownfield redevelopment.
- Economic Development: Working with the city manager and chamber of commerce, student teams developed marketing strategies and recommended new parking and transportation plans.
- Community Development: Working with a local community center, students developed a “green” building design to attract external funding for development.
- Public Safety: Working with the Parks Commission, students developed an auditing and maintenance system to reduce injuries at the city’s playgrounds.
- Education: Working with Worcester Public Schools, a series of project teams helped develop and evaluate a state-mandated curriculum in engineering.
- Environmental Protection: Working with the Greater Worcester Land Trust, a student team mapped land-use history to prioritize acquisitions for conservation.

Faculty-conducted program reviews of the IQP have indicated that students demonstrate high achievement of learning outcomes at the project centers, where projects bring students into direct engagement with local organizations and issues. WPI has found that students perform at their highest levels when tackling real-world problems that help them see how their knowledge and skills can be put to use in ways that are meaningful and useful to others outside of the university.

Conclusion
To prepare students for responsible leadership in an increasingly interconnected and technological world, colleges and universities are seeking strategies for connecting science and technology education with civic and social understanding. Engaging students in community-based problem solving can help students see science and technology in the larger contexts of public policy and quality of life while also promoting collaborative capabilities, critical thinking and communication abilities, and professional skills.

To engage students of science and technology in meaningful problems, institutions need look no further than their own communities. Municipal offices, community development organizations, and school systems are typically beset with challenges that can benefit from student and faculty work, and can serve as settings for rich and powerful learning experiences. High levels of engagement are likely when students are asked to address compelling, real-world problems in collaboration with local organizations.

Today’s students of science and technology will grapple with tomorrow’s challenges of energy and the environment, public health, infrastructure, public safety, and urban sustainability. The extent to which scientific and technological advance will be responsive to those challenges depends largely on whether our students learn to make wise decisions as professionals and citizens. Now is the time to help our students begin to see science and technology in broader contexts.

References
Engagement (n): An act of promising, committing, becoming engrossed, occupied, interlocked, enmeshed, entangled, or otherwise involved.

What engages students? And what engages faculty in engaging them? Both of these questions need our attention as we consider how and why we should teach. The stakes are high. If students do not engage, they are unlikely to learn. And if we do not engage, we are unlikely to engage our students. Furthermore, if we do not engage, we miss out on opportunities to learn ourselves. Thus, the engagement of all involved in the teaching and learning processes would seem to be a worthy and mutually beneficial goal.

Worthy or not, engagement is no simple process. It involves the commitment of self and energy from students and instructors. And even with such a commitment, engagement may remain an elusive goal. These observations serve as the rationale for the assertion made in the title; namely, that engagement is an art.

Engaging one’s students is not simply a matter of dutifully following a set of rules. Rather, like any art, engagement requires creativity and must be developed and continually practiced. In short, the art of engagement is worthy of reflection and study over the entire span of one’s teaching career.

A Philosophy of Engagement

I teach a large general chemistry course for non-science majors. In my experience, these students are smart, multitalented, and themselves engaging, although occasionally a bit science-phobic. Recently, a student from this course e-mailed me:

After taking the final today, I realized how great it felt to take a test after learning about things that I really care about. I never wanted to take chemistry in college—I came into this class thinking of it as nothing more then a prerequisite. But you changed something for me.

What changed for this student? Although several explanations are possible, I propose that at some level, she engaged. As is common for many nonmajors in our science courses, she was not taking the class by choice. Yet something changed her mind, and many others over the years have echoed similar sentiments.

My students are diverse. In terms of their area of study, just over a third are from the College of Letters and Science, and many have yet to declare a major. Another group (20 percent) is from the College of Agriculture and Life Sciences, including majors such as biological aspects of conservation and agricultural journalism. Nurses are required to take one semester of chemistry early in their program and usually elect this course. Elementary education majors also often elect this course and co-enroll in a learning community designed to help them prepare chemistry activities for their future classrooms. No matter which areas of study students bring, these are an asset for me to tap. In exploring the complexities of real-world problems, the prior knowledge, interests, and experiences of students serve as a resource for classroom interactions. As my colleague Conrad Stanitski from the University of Central Arkansas once cautioned, “Don’t let your students park their majors at the door.”
My students also enroll in large numbers, that is, 150 to 300 each semester. In the spring, the number is lower, presumably because of the timing of the course with respect to their major. In either semester, the course carries five credits and has no math prerequisite. The course meets three times a week for lecture, twice for small discussion sections with a graduate teaching assistant (TA), and once weekly for lab. My role includes both engaging the students in the lecture component of the course and creating an atmosphere in which the TAs can most readily engage the students in the other activities of the course.

Engagement in Content
Finding a “content hook” is one way to engage students in their study of chemistry. To be successful finding a hook, you must know your audience, know your subject, and find a connection that strategically brings the two together. Personally, I have found three types of hooks that work well: intriguing questions; current issues/concerns; and topics that speak to our common human condition, such as life, death, sex, and food.

For example, my approach to nuclear chemistry utilizes all three: an intriguing question (how can radiation both cause cancer and cure cancer?), a current issue (what is a dirty bomb?), and a connection to an issue of life and death (cancer treatment). Given how quickly the world is changing, I continually must change my approaches.

Nuclear chemistry is one of five real-world topics that I teach from the textbook *Chemistry in Context* (2005), a project of the American Chemical Society. This book has a philosophy of engagement: *to teach through real-world issues to the underlying chemical principles.* For example, teaching through the issue of global climate change might be represented as shown in Figure 1, and teaching through the issue of nuclear power as shown in Figure 2.

By design, each chapter of *Chemistry in Context* starts with a hook. It can be an intriguing storyline, a photograph, a pair of opposing quotes: in essence, anything that has the capacity to engage the reader. Frankly, finding these hooks has been an ongoing challenge for me and for the authors of the text. In part, the difficulty lies in our knowing what might intrigue today’s students. For example, although tales of the nuclear accident at Chernobyl might hook students on the topic of nuclear chemistry, a recent survey of my students revealed that half had not even heard of Chernobyl. Another difficulty lies in the varied interests of students: what interests one may not interest the person sitting next to him or her, and what is successful in catching the interest of students one year may not even appear on the radar screen of those the next. Clearly, selecting the hook involves both a working knowledge of current society and culture and the ability to hit a moving target.

Engagement at Multiple Levels
Engagement is more than simply selecting content. Equally vital is to simultaneously engage students at several levels, including their lives, our own lives, and the world in which we all live. These levels are interconnected in complex and meaningful ways. Furthermore, as we successfully engage our students, they in turn will engage us. Truly this synergism characterizes teaching as no other profession. Of all these levels, engaging students through stories of our own lives perhaps elicits the strongest reactions to the contrary. I have heard colleagues say that they never would want to reveal personal information to
their students. They speak of the personal discomfort they would incur in doing so or of their need to maintain a proper distance from their students. I also have heard the admonition that we should not talk about extraneous content (such as our own lives), because doing so would be both unprofessional and wasteful of precious minutes of class time.

Although truth underlies all of these arguments, my own experiences in the classroom speak to the contrary. When I teach, remaining distant from my students simply doesn’t work. In truth, it never has worked for me, and I suspect it never will work. Most simply put, if I disconnect from myself, I disconnect from my students. In turn, they disconnect from me. Assuredly, there are topics that I don’t reveal in the classroom; in fact, I may never reveal them to another human being. But this is the exception, not the norm. Most of my hopes, fears, dreams, and life experiences can claim a rightful place in the classroom.

Does this mean that we must reveal our innermost selves to our students? Not as such, but I do believe that we should select relevant parts of our lives to reveal. If we allow them to, our personal stories can become woven into the daily rhythms of teaching. Some stories are told one semester; others told another. Some stories get told repeatedly, others never again, and some stories never get told in the first place. The art is in selecting the story that fits the needs of the moment: encouragement, humor, drama, tales of those before us, or our hopes and fears from the past and for the future.

One caution: telling personal stories does not mean “dumping” our personal lives into the classroom. It also does not mean appropriating large chunks of time that distract from the task at hand. How do you evaluate the effectiveness of your own personal storytelling? In part, you learn through experience—feedback from your students will help you gauge the effects. The art lies in telling stories to open paths of communication, especially to those who have not trod the ground before and are glad if somebody else can point the way.

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The Courage to Engage
Frankly, I never expected to be so engaged in teaching non-science majors. In planning a career path, the possibility of spending so much time teaching those not in my field never crossed my mind. But once my students engaged me, I was hooked, and perhaps rightly so. In my earlier attempts at finding a hook that would engage my students, I found myself on the hook as well.

Parker Palmer writes in *The Courage to Teach* (1998), “We did not merely find a subject to teach—the subject also found us.” I strongly agree. Real-world topics such as nuclear radiation, plastics and recycling, and smog found me. With these and other issues that deeply affect all of us on this planet, I became engaged. In turn, I hope to engage my students in the complexities of these issues. Furthermore, I would assert that “we do not merely find students to teach, the students also find us.” And once they do, a certain amount of courage is required on our part. Why courage? For at least three reasons:

- First, to engage students you have to know and connect with them. This is not for the faint of heart; you will be drawn into their worlds in ways that are perhaps unfamiliar or uncomfortable.
- Second, once you engage students, they will engage you as well. This engagement has a cost in time and energy, and you will discover the boundaries you can cross, the personal frontiers you can negotiate, and those which (for a variety of reasons) you simply cannot.
- Third, engagement carries an intellectual challenge.

To explain this intellectual challenge, please allow me to offer an analogy. When teaching a first-year course, I often feel as if I were teaching a special-topics course at the graduate level. With the topic of ozone depletion, for example, I must update my syllabus with each new finding: a press release from NASA, an international meeting to amend the Montreal Protocol,
news about the breakup of a Freon smuggling ring, a recent industrial accident with ammonia, or new findings about the chemistry of chlorine in the upper atmosphere. Whew! I sometimes long for the days when I could simply pull the same old titration problems off the shelf year after year. It truly takes courage to commit to a course that in turn commits you to such a serious degree of engagement.

When we expect to engage our students quickly and with minimal effort, we deny the very art form of engagement.

Practicing the Art of Engagement
I return to an assertion made in the title: Engagement is an art worthy of a lifetime of reflection and study. It comes neither easily nor cheaply, but rather with a personal commitment and a willingness to practice. This art involves making good choices about the content that is taught and about one’s personal involvement in the teaching process; it also requires the ability to recognize the subtleties and challenges of the larger learning context for both our students and for ourselves.

Think for a minute about practicing any art: a musical art, a martial art, or a medical art. The “practice” needed for any of these involves a significant commitment of self. Engagement is no exception. With one attempt at engagement, we may overdo it at too great a personal cost. With another, we may underdo it, failing to connect to either ourselves or to our students. When we expect to engage our students quickly and with minimal effort, we deny the very art form of engagement. By embracing the need to practice, we find paths of engagement that work for us, for our students, and for the world that connects us.

Any art also requires a willingness to enter it as a beginner. Beginners can allow themselves to feel clumsy. With their minds and hearts set on the goal of improving their practice, beginners can act ineptly or ungracefully. Beginners are free to seek the counsel of teachers and other experts. Fortunate is the beginner willing to practice in the company of one who shows mastery of the art! Equally fortunate is the expert who can hold the openness of “beginner’s mind.” If we fail to embrace our status as a beginner, we lose the freedoms we need to learn.

The Challenges
A recent issue of Chemical & Engineering News, the weekly journal for members of the American Chemical Society, reported on a conference aimed to reform the chemistry curriculum. The speakers addressed topics relating to the curriculum that we offer our chemistry majors. One speaker, Judith A. Ramaley, then assistant director of the National Science Foundation Education and Human Resources Directorate, pointed out that Major curricular reform must be grounded in a clear institutional mission and a coherent educational philosophy. Such reform is not about transmitting the knowledge of chemistry. It’s about drawing people into the world of chemistry.

I couldn’t agree more. And for both our majors and our nonmajors, I also would add: “It’s about drawing chemists into the world of people.” Engagement of our students cuts both ways. We must draw our students into our intellectual world. But we as teachers must be drawn out into the world of our students as well. At issue here is the human journey we all share. Our chemistry courses, especially those for our students studying other liberal arts, need to connect with this human journey.

References
Both humanists and scientists need to grapple with the ethical and social issues presented by science and technology. Many issues in contemporary politics and social policy derive from the social consequences of scientific and technological developments. The votes of average citizens determine the funding and implementation of many policies that involve science and technology. Nonscientists need to be able to distinguish scientific evidence from political propaganda and pseudoscience. They need to be able to separate genuine scientific data from rhetoric and propaganda used to advocate policy positions. Despite the ever-growing body of scientific knowledge to convey to undergraduates in lectures and laboratories and the increasing importance of science and technology to society, there is even less room in science courses to cover the social issues of science and technology. As a result, more institutions are working to incorporate the sociology and history of science into integrative general education programs for all students. This is not an easy task. In this article, we discuss the imperative for this trend, the barriers to integrating the sociology and history of science into the curriculum, and an approach to science studies adopted by the University of Southern Maine at Lewiston-Auburn (USM-LA).

In today’s world, students are bombarded by “scientific” claims. Even science majors often lack the conceptual tools to evaluate pseudoscientific claims outside their specialties. In our own teaching, we have encountered physics majors claiming to have magical and psychic powers and senior biochemistry majors who believe in young earth creationism. Additionally, many students have a naive and simplistic conception of the relation of science to technology and lack an understanding of the social, ethical, economic, and political dimensions of science and technology.

Knowledge and skills in the sciences and in technology are of growing importance in modern life. Colleges struggle to provide an appropriate balance between science and the other disciplines in the curriculum. Likewise, many current revisions of general education stress interdisciplinary approaches and a focus on civic-mindedness. Increased “scientific literacy” can result from creatively weaving the history, sociology, and philosophy of science and technology (science studies) throughout general education curricula.

The History, Sociology, and Philosophy of Science
There are several strands of recent scholarship that can inform efforts to incorporate these important science studies issues into the general education curriculum.

Through the study of the history and philosophy of science, students come to realize that there are, in fact, a number of different scientific methods. A historical perspective can teach students that different scientific disciplines today emphasize different methods, systems of logic, and even notions of epistemology than they did in other historical periods. For instance, some sciences have been primarily descriptive, such as natural history or early astronomy. Other sciences have been primarily inductive and experimental; earlier in the history of physics and chemistry and later in biology and psychology. Still other sciences have been primarily deductive, such as earlier celestial mechanics or string theory today.
Recent scholarship on the relation between science and technology can also be very useful in these courses. Because of the extent to which an understanding of technology depends on theoretical science, many people assume that technology is simply pure science applied. Students may not understand how social and political concerns influence technological choices and developments or the extent to which technological innovations are the result of tinkering and accident.

Finally, arguably the newest and most controversial strand of scholarship is the sociology of scientific knowledge, which builds on the insights of Thomas Kuhn and addresses the role of authority, negotiation, and prestige in the growth of scientific consensus about a fact or theory. This scholarship is useful in helping students see how factors not usually considered “scientific” or even “rational” have influenced science over the years.

**Barriers and Challenges**

These strands of scholarship are not without controversy, especially among practicing scientists. Thus, the task of incorporating them into general education programs and courses presents several challenges.

Although some scientists are skeptical about these approaches, progress is definitely possible. Several decades ago, a microbiologist informed us that there were no ethical issues in biology, and that such issues only arose in physics (e.g., nuclear warfare). That same colleague now teaches a course on the ethics of genetic engineering. Some scientists do not “believe” in a philosophy or sociology of science. One colleague of ours suggested to us that we stay out of the natural sciences and “stick to sociology.” One of us was questioned by an aged engineer on how ethics of technology could be stretched into a whole semester course, believing that the issues would take less than fifteen minutes. Few engineers today would make that claim.

Whatever the barriers, the challenge before us is to undermine simplistic, mechanical views of scientific progress as an automatic and nonhuman process. Yet, in undermining the logical fallacies and historical myths about science and technology, we must also teach students to recognize that there is a difference between truth and falsehood, between well and poorly done science, and between moral and immoral behavior. The most difficult task for educators is to help students to learn to be open-minded yet critical, and to walk the fine line between apathetic skepticism and passionate dogmatism.

This task may be even more difficult with science studies. Still, many state K-12 science curriculum standards demand student learning on the social, philosophical, and applied issues of science, so institutions of higher education need to build on this foundation. It is obvious that science and technology are central to understanding human life and society today. This centrality needs to be reflected across general education.

**The Experience of a Small, Interdisciplinary College**

Although fewer science departments seem to require all students to take a history or philosophy of science course, many colleges are implementing interdisciplinary general education courses that address the sociology and history of science. At the University of Southern Maine at Lewiston-Anburn, science studies are infused across the general education curriculum.

USM-LA is a unique public institution. It is a small, interdisciplinary college of the USM system with four interdisciplinary majors run primarily by twenty-four full-time faculty. The faculty collaborates on curricular planning, and there is a focus on faculty development, pedagogical innovation, and the scholarship of teaching and learning.

Our developing curriculum currently themed “How, Then, Shall We Live? Citizenship in a Global Society,” includes a required course on technology, science, and society. Science-related, interdisciplinary topics are also addressed in a general education course on wellness. For the required ethics course, “investigating the role of science in moving us toward or away from global ethics” is identified as an outcome. Addressing specific global scientific and technological concerns are also proposed as outcomes for a two-course sequence on globalization.

During the development of the curriculum, the general education design team requested that a faculty member with a background in science studies provide a workshop to all faculty. This workshop launched a discussion of cross-disciplinary epistemological issues and areas of bias in particular disciplines. The faculty chair believed the workshop was “instrumental in moving the faculty through difficult moments of conceptualizing how we might bridge the gap between science and political engagement.” The example of USM-LA shows it is possible for science studies to be better and more centrally integrated into general education programs.
This Peer Review issue focuses on science and engaged learning. As any advertising executive or politician can tell you, engaging people is all about attitudes and beliefs, not abstract facts. There is a lot we can learn from these professional communicators about how to effectively engage students. Far too often we, as educators, provide students with the content of science—often in the distilled formal representations that we have found to be the most concise and general—but fail to address students’ own attitudes and beliefs. (Although heaven forbid that we should totally abandon reason and facts, as is typical in politics and advertising.)

What does it mean for students to be meaningfully engaged in learning science? I would argue that it means that students are both actively thinking about the subject and applying scientific ideas to solve problems, in much the same manner as an expert. So how well are our science courses accomplishing this? Recent research (including some from my own research group) has measured students’ attitudes and beliefs about physics and physics problem solving and how introductory physics courses affect these beliefs. What is consistently found is that completing such courses actually shifts students’ beliefs to be less expert-like. For example, a large fraction become convinced of such statements as, “To solve a physics problem, I should look for an equation that has the variables given and just plug in the values.” Or they believe statements like, “The subject of physics has little relation to what I experience in the real world,” or “I cannot learn physics if the teacher does not explain it well in class.” This shift towards less expert beliefs is seen even for courses that incorporate a number of “interactive engagement” methods associated with good conceptual learning gains. We also see direct evidence that student beliefs are very important: they correlate with learning gains, course retention, and the inclination to pursue (or switch out) of physics as a major. Although most of the data comes from physics, our sampling of courses in other sciences shows similar negative impacts of instruction on student beliefs.

If we are going to seriously engage students in learning science, we must attach as much importance to student beliefs, and how different teaching practices affect those beliefs, as to the content we cover. We must recognize that when we present material in formal, abstract ways, use unnecessary technical jargon, and assign homework and exam problems that are correspondingly abstract and can be completed by following memorized recipes, we are teaching more than just content. To a student who does not share our experience and expert insight, we also teach that the subject is abstract and disconnected from the real world, that problem solving is basically rote memorization, and that there is no use for solving a science problem other than to pass a course.

This needn’t be the case. With a little effort, virtually all introductory content can be presented in terms of understanding the behavior of real-world phenomena, with little or no obscuring technical terminology. We can also learn from advertising how to choose those illustrative phenomena that will most attract and interest students in the subject. Problem solutions can require reasoning and have obvious real-world utility. I have found that rather modest efforts of this sort have a substantial impact on the beliefs about physics for science and nonscience majors.

Only when we recognize that education is more about changing student minds than transferring information, and guide our teaching and evaluation of learning accordingly, will we be able to truly engage and educate students in science.

The opinions expressed in the article do not necessarily reflect the official position of the National Academy of Science.
Interest in adopting “pedagogies of engagement” in science teaching has sharply increased over the last decade. It turns out this is not a passing fad, but more a realization that teaching strategies that are consistent with research on learning must engage learners in constructing and making sense of their own knowledge. The contemporary view of learning, based on a large body of evidence from research studies, indicates that learners not only construct knowledge, but the knowledge they already possess filters any new knowledge that they are trying to learn. If new knowledge conflicts with previously constructed knowledge, the new knowledge will not make sense to the learner and may be constructed in a way that is incompatible with current scientific thought, or perhaps not useful for flexible application. Hence, sense making is central to the constructivist view of learning.

Constructivism has important implications for learning and instruction. First, construction of knowledge does not just happen in the classroom; rather, it is a lifelong, effortful process requiring significant mental engagement from the learner. Further, since resident knowledge filters the ability to construct new knowledge, it is important to keep in mind that the learner’s mind is not a blank slate upon which new knowledge can be inscribed. Each learner comes into a classroom with a brain already wired by previous experiences. Depending on the existing connections, even the same concrete experiences are perceived differently by different learners.

From the perspective of instruction, teachers would be wise to probe students’ previously constructed knowledge in order to make appropriate instructional choices so that students construct knowledge in ways that the teacher intends. Teachers then need to determine whether sufficient prior knowledge is available and evaluate whether this knowledge conflicts with the knowledge being taught. If conflict does exist, teachers should guide learners in reconstructing knowledge. The goal is to facilitate knowledge construction in learners that is compatible with scientific concepts so that learners will store the knowledge in memory in a form that is optimal for long-term recall and for application in problem-solving contexts (Etkina, Mestre, and O’Donnell, forthcoming). To ignore learners’ preexisting knowledge makes it highly probable that the message intended by the teacher will not be the message understood by the student.

The most relevant, and perhaps obvious, instructional implication of constructivist epistemology is that teaching strategies that facilitate the construction of knowledge should be favored over those that do not. What, then, are pedagogical strategies that foster, encourage, and facilitate the construction of knowledge? Many pedagogies of engagement have emerged over the years with names such as cooperative or collaborative learning, active learning, case-based learning, and hands-on learning. All of these instructional strategies attempt to create an environment where students are actively thinking about and applying knowledge during the course of instruction, as
opposed to passively listening to an instructor present the material in the textbook. This approach places more responsibility on the learner by expecting her or him to come to class prepared and ready to work at the difficult task of refining conceptual understanding and developing problem-solving skills.

The Emergence of Pedagogies of Engagement in Physics

An interesting series of events led to a sharp increase in the development and adoption of different forms of active learning in physics. Over twenty-five years ago, physicists and educators had begun to realize that students in physics classes, both in high school and college, had strong beliefs about how the physical world worked—beliefs that were in conflict with how physicists described the world. Physics education research at the time largely consisted of exploring how what came to be known as “misconceptions” interfered with the learning of physics concepts. Word about students’ misconceptions had begun to trickle down to professors teaching introductory physics, but most paid little attention to the implications of this work for instruction; the view appeared to be that good professors were able to help students overcome these erroneous ideas with appropriate clarity and organization in the lectures.

Then, in the mid-1980s and early 1990s, David Hestenes and his collaborators (Halloun and Hestenes 1985; Hestenes, Wells, and Swackhamer 1992) developed and refined a simple test of basic misconceptions in mechanics that came to be known as the Force Concept Inventory (FCI). Figure 1 shows two questions from this test, which should make it evident that the FCI measures understanding of basic conceptual knowledge that physicists expect students to grasp after taking an introductory physics course. The FCI had a pronounced effect on dialogue among physicists about pedagogy, but the mechanism by which this dialogue began was somewhat amusing. Many who knew about the adverse effect of misconceptions on learning invited professors of introductory courses to administer the FCI to their classes at the end of the course. At first, not many took up this offer, stating that it was a waste of time to give such a basic exam to students following instruction since students would surely get all of those easy questions correct. As those few who actually administered the FCI quickly realized, students were finishing introductory courses and earning very good grades and yet had a very poor grasp of the concepts underlying the equations that they were adept at manipulating.

An anecdote that physics professor Eric Mazur at Harvard often tells about his personal experience with the FCI exemplifies the situation. Mazur tells that he was among those who thought that his students would surely know the answers to all of the questions in the FCI, but decided to try giving the exam to his class. He immediately knew that something was wrong when a student raised her hand and asked him whether he preferred that she answer the questions according to what he taught them, or according to what she really believed to be true. This incident was an epiphany for Mazur, who later developed and adopted an active learning approach that he calls “peer instruction” (Mazur 1997). What eventually became clear was that students taught via active engagement methods had much higher pre-post gains on the FCI than students taught by conventional lecture methods (Hake 1998), and furthermore, the charisma of the instructor had little to do with student gains on the FCI.

Features of Active Learning

There are several features commonly found in pedagogies of engagement:

- Students are actively engaged in constructing knowledge, often by working collaboratively on meaningful questions that are discussed within the context of concepts and procedures being covered in class, or of previously constructed knowledge. The questions do not have to be difficult, but care should be taken by the instructor so that they illustrate the meaning or application of major ideas in the course (e.g., questions that elicit possible misconceptions are very useful).
- Students voice the reasoning leading to their answers for evaluation by peers and by the instructor. Students thereby learn about constructing coherent arguments as well as evaluating arguments, and
teachers play the role of learning coach rather than dispensers of information.

- Class time is largely spent on refining conceptual understanding and on exploring procedures for applying conceptual knowledge across multiple relevant contexts. This helps students construct knowledge that is consistent with current scientific understanding and can be flexibly applied.
- Students rely less on the teacher as an authority figure, or as the “keeper of the knowledge,” and take more responsibility for becoming self-sufficient learners. The focus of pedagogies of engagement is on the student, not the instructor.

Myths about Pedagogies of Engagement

I believe that several myths prevent pedagogies of engagement from being the norm in college science instruction:

- Myth 1: Pedagogies of engagement result in less content being covered and this is a disservice to students. Part of this “myth” is grounded in fact—it is virtually guaranteed that the time needed to address students’ difficulties during instruction means that less content will be covered, but just because active learning is less efficient for covering lots of content does not mean that we are doing students a disservice. Keep in mind that covering lots of content in class does not mean that students learn it, at least at the level and with the longevity that we desire. Active learning focuses on helping students understand somewhat less material but at a much deeper level, and this has more lasting effects than covering large amounts of content superficially.
- Myth 2: Research on learning indicates that all lecturing is bad and to be avoided. Not so. Although it is true that lecturing exclusively is not the most efficient way to help most students construct knowledge during class, there is nothing in the research literature that states that lecturing is useless for learning. In fact, there is research that hints at when lecturing is most effective. Bransford and Schwartz (1999) have shown that certain active learning activities prepare students to learn from lectures that follow those activities, even when little apparent progress is made in achieving the goals of the activity. These findings suggest that the activity primed students to learn from the subsequent lecture in a way that was not possible by lecturing alone.
- Myth 3: I’m a great teacher because I get excellent teaching evaluations, and so there is no need to change my lecturing. Unfortunately, teaching evaluations are not designed to measure how much students learn. Often they measure the charisma, showmanship, or popularity of the instructor. It would seem that instructors who consistently receive high teaching evaluations would be open to trying something new that might result in more learning in students, but my experience suggests the opposite.
- Myth 4: Any activity that makes students active during class will result in more learning. It is important to design classroom activities in ways that are optimal for the outcomes that the teacher desires, and this takes effort and experience. Having students discuss whether they liked yesterday’s weather will not help them learn meteorological concepts.
- Myth 5: Having students present their reasoning during class confuses other students and therefore is not worth the effort. This is an argument that I often hear from many of my own students; they would rather that I just explain things because, they claim, listening to several erroneous arguments presented by other students causes them to remember wrong information. My counterargument to them is that equally important as constructing good arguments is judging the validity of arguments—a skill that scientists value highly.

Final Thoughts

While it is certainly true that much progress has been made in the last few decades on the nature of human learning
and on effective teaching strategies, much remains to be determined about the definitive conditions that produce successful learners. However, in refuting the previously stated myths that all too often prevent pedagogies of engagement from being utilized in the classroom, it is clear that many of the commonly accepted views on how students learn should be challenged. Research has shown that through true pedagogies of engagement—actively engaging students in constructing knowledge with adequate classroom time for refining conceptual knowledge—we can create effective learning environments.

**Figure 1:**
Two questions from the Force Concept Inventory. All questions in this exam measure understanding of basic concepts covered in the typical introductory physics course.

*FCI Question #12 (Cannon)*
A ball is fired by a cannon from the top of a cliff as shown above. Which of the paths 1-5 would the cannon ball most closely follow?

*FCI Question #23 (Airplane)*
A bowling ball accidentally falls out of the cargo bay of an airliner as it flies in a horizontal direction. As observed by a person standing on the ground and viewing the plane as in the above figure, which path would the bowling ball most closely follow after leaving the airplane?

(Artwork by Sanjay Rebello, used with permission.)

**References**


Highlights from AAC&U Work on Science and Health

AAC&U works to advance broad-based systemic innovation to connect science education, especially in general education, to large public questions where scientific inquiry and knowledge are essential. AAC&U also works to support educational leaders in developing an academic focus on health and HIV disease to improve student learning and our common health. AAC&U’s work in these areas focuses on improving science education for students who may never major in a scientific field; connecting science reform to more robust and relevant general education programs; encouraging curricular attention to issues of gender and science; and stimulating informed civic engagement with scientific questions.

A more comprehensive listing of AAC&U’s current work on science and health, as well as links to additional information on the various projects and publications, can be found online at www.aacu.org/issues/scienceandhealth/index.cfm

Program on Health and Higher Education (PHHE)

For nearly a decade, PHHE, as an AAC&U project, has engaged higher education in placing rigorous academic focus on the prevention of HIV infection and on other complex health issues in an effort to improve undergraduate learning. PHHE was founded, in part, on the notion that the academic engagement of social issues such as HIV/AIDS, can foster collaborative problem solving, interdisciplinary learning, social responsibility, and civic engagement.

PHHE is designed to curricular attention to HIV and other pressing, unresolved problems in community health by providing resources to support college instructors and sustaining a network of student-led, academically based initiatives.

To locate HIV within higher education, PHHE makes two complementary arguments.

The multidisciplinary and societal issues raised by HIV provides compelling ways to

- illustrate the benefits of liberal learning;
- strengthen science and medical education’s connections to higher education’s civic mission;
- assess students’ ability to solve problems through making connections between and across different ways of knowing, different disciplinary tools, and different cultural traditions;
- engage the academy in institutional change to prepare students for a globalized world increasingly defined by social dichotomies—environmental preservation and development, health and vulnerability, peace and security, resources and equity, and democracy and freedom.

An engaged academy possesses enormous potential to create conditions that would

- prevent the spread of HIV, especially in youth;
- improve individual and community health;
- enhance graduates’ sense of responsibility for individual, civic, and social choices; and
- enhance collaboration with communities locally, regionally, nationally, and globally to eliminate health disparities.

PHHE is funded by a cooperative agreement (00081) with the U.S. Centers for Disease Control and Prevention (CDC), Division of Adolescent and School Health (DASH), Atlanta, Georgia.

www.aacu.org/phhe

LEARNING FOR OUR COMMON HEALTH: How an Academic Focus on HIV/AIDS Will Improve Education and Health

A collection of eight essays by distinguished leaders in higher education and health. The book lays a foundation for a new scholarship of civic engagement, explores a reconceptualization of health that embraces “common health,” and suggests how an academic attention to HIV/AIDS fits with the current best thinking about education reform. Particularly useful to those engaged in strategic planning, curriculum development, civic engagement, and improving collaboration between academic and student affairs departments.

www.aacu.org/publications
Bringing Theory to Practice (BTtoP)

The Bringing Theory to Practice (BTtoP) Project, sponsored by the Charles Engelhard Foundation of New York City and developed in partnership with AAC&U, advocates the academic community’s support of engaged learning and explores the relationship of such learning to student health and civic development. Now in its second year, the project has been appraising whether and how specific forms of engaged learning (including, but not limited to, service learning and community-directed collaborative research) can be effective elements in intervention or prevention strategies designed to address two debilitating challenges for our students: substance abuse and depression.

The pedagogies of engaged learning require significant intellectual commitment from students; they call upon students to use contexts for learning (including the community) that intentionally go beyond the classroom and beyond information transfer. Students take greater responsibility for learning and involvement, and doing so promotes both their own well-being and their sense of civic responsibility. The research aspect of the project seeks understanding of the nature and extent of the relationships among identifiable forms of engaged learning, the pedagogies that support them, and their effects on the mental health, the behavior, and the full development of students. Research also examines the connection of engaged learning to the conditions of citizenship necessary for an open democratic society.

“The whole of the academy could more effectively address the context in which students learn. Understanding and encouraging resiliency allows students to address the challenges of abusive behaviors and prevalent forms of mental health disorders,” said Donald W. Harward, project director. “Doing so recognizes three fundamental, and interrelated, objectives of learning: gaining and promoting knowledge and discovery, supporting the self-realization of individual learners, and encouraging their civic development.”

The project is guided by an interdisciplinary planning group of scholars, researchers, practitioners, and institutional leaders. Currently, over forty colleges and universities are linked, many supported by grants, in discussions of these topics on their campuses. Funds from the project support campus programmatic initiatives, and, in response to a call for proposals, sixty-six campuses have now applied to be demonstration sites, allowing them to identify, develop, and access models which may be transferable to other institutions.

This year, the BTtoP Working Conference will be held April 15-16, 2005, in Washington, DC. Details regarding the conference, copies of published reports, information regarding other strategic initiatives now undertaken by the project, and information regarding grant support are available online.

www.bringingtheorytopractice.org

Other AAC&U Science Publications

GENDER, SCIENCE, AND THE UNDERGRADUATE CURRICULUM: Building Two-Way Streets
This anthology emerges from AAC&U’s curriculum and faculty development project, Women and Scientific Literacy: Building Two-Way Streets. The project examined core questions such as “How can things be done differently to increase the numbers of women who study science, math, and engineering?” and “How will the new scholarship about women and gender alter science itself and how science is understood both within its own disciplines and beyond?” The essays in this book demonstrate ways to integrate this new scholarship—known as feminist science studies scholarship—and new teaching practices into basic science courses, for nonmajors as well as majors, and into women’s studies courses.

WARMING THE CLIMATE FOR WOMEN IN ACADEMIC SCIENCE
Provides a comprehensive review of women’s status as undergraduate students, graduate students, and faculty members in science, mathematics, and engineering. Presents recommendations for actions that can be taken by undergraduate and graduate students, faculty members, administrators, and professional organizations. Includes a resource section of bibliographies and organizations.

www.aacu.org/publications
Who doesn’t like a good story? Teachers and parsons have used them to perk up their students and parishioners from time immemorial. Stories capture our attention, entertain us, stir our emotions, and expand our visions. Preachers use them for moral persuasion, comedians to tickle our funny bone, and teachers as exemplars of good practice.

The formal use of stories, called case studies, was introduced into Harvard University’s law and business schools around a hundred years ago. Professor Charles I. Gragg extolled the virtues of the method sixty years ago in an article with an eye-catching title (to which this article’s title pays homage), “Because Wisdom Can’t Be Told.” The title itself emphasizes the truism that simply lecturing students about a subject hardly ensures that they will remember anything at all. The medical profession has known this for a long time. They have always used case studies to instruct their interns and residents with “war stories,” but the whole process wasn’t formalized until thirty years ago, when McMaster University introduced the storytelling method, Problem Based Learning (PBL), into their medical school curriculum. Today case-based teaching has gone well beyond these graduate programs, especially in science and engineering.

Two groups are arguably responsible for most of the excitement: the University of Delaware and the University at Buffalo-The State University at New York (SUNY). Both institutions have been the grateful recipients of generous grant support from the U.S. Department of Education, the Pew Charitable Trusts, and the National Science Foundation (NSF) for the past decade. The University of Delaware has enthusiastically promulgated the PBL approach across the country and urged its adoption in every undergraduate discipline on campus.

We at the University at Buffalo have been less eclectic. Mindful of the surveys that claim that most U.S. citizens are scientifically illiterate and that there is a disastrous loss of student interest in science throughout the secondary and college years, we have focused our attention on these problems. And we personally know some shocking statistics about introductory science classrooms at large universities. It is not uncommon for 30 to 40 percent of the students to receive Fs, Ds, or withdraw. This statistic seems to be true regardless of the skill of the instructor. Not surprisingly, attendance in these courses is also terrible. Even fine lecturers often end up with less than 50 percent of their class present. Can this situation be completely the result of the immaturity of the students, their lack of motivation, or the fact that many of them work long hours outside of the classroom? Is none of it our fault? Many faculty seem to act as if it is beyond their control. But is that true?

I am especially fond of the sentences uttered by the Swiss developmental psychologist Jean Piaget: “At one time every teacher ought to have been an animal trainer. When the animal doesn’t do the trick, you don’t blame the animal. You blame the trainer.” And change the method of training, of course.

Changing the Training

There are lots of ideas about how to change the training. Most of them involve active learning—getting students to do something rather than passively receiving wisdom. Our approach at the University at Buffalo has been to capitalize on the inherent interest that is sparked by stories. Not stories simply for entertainment but “stories with an educational message.” Of course, the stories can be told in a number of different ways:
through lectures (such as when I give a lecture in the first person as Charles Darwin); as a written story, video, or movie with a discussion following—the method treasured by business and law schools; as a PBL problem, which can be presented to small groups of students; or even through one-on-one discussion, with a professor sitting on one end of the log and the student on the other. All these case-study approaches are important alternatives to the standard lecture. And we vigorously proselytize all who will listen. We have a national Web site supported by NSF where several hundred cases and teaching notes are posted (http://ublib.buffalo.edu/libraries/projects/cases/case.html). We hold workshops and conferences and distribute cases in publications such as the Journal of College Science Teaching, which runs a regular column and has an annual issue completely devoted to cases across all fields of science.

Teaching with cases rather than lectures places different sorts of demands on both teachers and students. When you give up significant control of the classroom and actually let the students talk, who knows how the conversation will turn out? And how will you grade the students? Such questions can make anyone anxious. It is understandable if faculty approach the new methodology with some trepidation and skepticism. So, it is important to highlight some of the things that we have learned about this new approach:

- The story of a good case study should be based upon real events, have engaging characters, include dialogue, be short, and have relevance to the students’ lives. And it should be a “dilemma case,” which means it involves decisions that must be made by the characters and students.

Ideally we want a case that engages students in the same way that a detective story does. One that mimics the kind of critical thinking that all scientists must do. Scientists often must reach tentative conclusions on the basis of incomplete information and then be willing to modify those conclusions as more data become available.

- Case method teaching causes attendance to soar. Even in large classes, attendance has approached 100 percent in our experience with this method.

- Students’ positive attitudes toward the subject matter increases. Most students report they love learning the material in context, something that the lecture method seldom accomplishes.

- Most students enjoy working in teams, but it is important to establish clear guidelines to ensure there are equal contributions from all students.

- The instructor cannot usually cover the same amount of material as in a lecture, but students retain what is covered better. The lecture method produces students who seem to forget material almost immediately after the final exam. Students who have been taught using cases perform just as well on standardized exams as students who are instructed by the lecture method, but they perform much better on essay exams where higher-level thinking skills are required.

**Survival of the Fittest?**

Most students indicate that they prefer learning with the case study method; nonetheless, about 15 percent of students still favor the lecture method, even when they have had a positive experience with cases. And those students are in good company—after all, most readers of this article are survivors of the lecture method and may never have experienced anything else in the science classroom. It is a Darwinian educational system that we have produced. Most students do not survive the process of learning science, therefore they go on to other fields. However, even in the face of mounting evidence of its ineffectiveness for masses of students, we survivors of the lecture method are reluctant to abandon our old friend. We seem to be the exception—ones to whom *Wisdom Can Be Told*. But we are few in number, and we have a much greater obligation than to our limited numbers. Transforming the science classroom is not beyond the faculty’s control. Through the use of PBL techniques, such as teaching with case studies, we can engage students, provide them with the means to learn how science works, and help them recognize the relevance of science to society.

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