2005

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

Judith A. Ramaley
Winona State University

Rosemary R. Haggett
West Virginia University

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 and professor, Animal and Veterinary Science, West Virginia University

We live in a period of rapid and complex socioeconomic 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. 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 predilections 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 tenure-track 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.

Acknowledgments

The authors would like to thank the following program directors in the NSF Division of Undergraduate Education--Susan Hixon, John Haddock, Herb Levitan, David McArthur, Jeffrey Ryan, and Jeanne Small--for raising some significant issues in undergraduate education with us; that discussion catalyzed this paper. We also thank Dr. Paul Feltovich of the Institute for Human and Machine Cognition for his careful reading of our manuscript and for his thoughtful suggestions.

References

Association of American Colleges and Universities (AAC&U). 2002. *Greater expectations: A new vision for learning as a nation goes to college.* Washington, DC: AAC&U.

Beichner, R. J. Forthcoming. Introduction to the SCALE-UP (Student-Centered Activities for Large Enrollment Undergraduate Programs) Project. In *Proceedings of the invention and impact conference.* Washington, DC: American Association for the Advancement of Science.

Bransford, J. D., A. L. Brown, and R. R. Cocking. 2000. *How people learn: Brain, mind, experiences and school.* Expanded edition. Washington, DC: National Academy Press. Online at www.nap/catalog/9853.html.

Business-Higher Education Forum. 2003. *Building a nation of learners: The need for changes in teaching and learning to meet global challenges.* Washington, DC: Business-Higher Education Forum.

Fagan, A. P., C. H. Crouch, and E. Mazur. 2002. Peer instruction: Result from a range of classrooms. *Physics Teacher* 40:206-9.

Goodman Research Group, Inc. 2002. *Final report of the Women's Experiences in College Engineering (WECE) project.* Cambridge, MA: Goodman Research Group, Inc.

Gosser, D., V. Strozak, and M. Cracolice. 2001. *Peer-led team learning: General chemistry.* Upper Saddle River, NJ: Prentice Hall.

Handelsman, J., D. Ebert-May, R. Beichner, P. Brus, A. Chang, R. DeHaan, J. Gentile, S. Lauffer, J. Steward, S. K. Tighman, and W. B. Wood. 2004. Scientific teaching. *Science* 304:521-22.

Levy, F., and R. J. Murnane. 2004. *The new division of labor: How computers are creating the next job market.* Princeton, NJ: Princeton University Press.

Mazur, E. 1997. *Peer instruction.* Upper Saddle River, NJ: Prentice Hall.

National Research Council. 2002. BIO 2010: *Transforming undergraduate education for future research biologists.* Washington, DC: The National Academies Press.

Novak, G. M., E. T. Patterson, A. D. Gavrin, and W. Christian. 1999. *Just-in-Time Teaching: Blending active learning with Web technology.* Upper Saddle River, NJ: Prentice Hall.

Patterson, E., and G. Novak. 2003. A JiTT approach to authentic learning: Teaching process with content. *American Association of Physics Teachers Announcer* 33 (4): 123.

Waterman, M. A., and E. D. Stanley. 2000. *Investigative cases and case-based learning in biology*, ed. J. R. Jungck and V. Vaughan. Vol. 6 of BioQUEST Library. San Diego: Academic Press. CD-ROM.