

ESSAY

There's a Pony in Here Somewhere! Reflections on Integrating Teaching and Research at Predominantly Undergraduate Institutions

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"It was the best of times, it was the worst of times."

Charles Dickens
A Tale of Two Cities

Our Nation is at a crossroads. Although far removed from the tragedies and chaos Dickens so poignantly described in his book, this dramatic paradox appears to have re-emerged in the American scientific community of the new century. The headlines in the scientific and popular press regularly highlight the budget crisis we now confront. The exploding federal budget deficit has sent a shiver through the scientific establishment as we ponder which programs will sustain the cuts necessitated by this deficit behemoth. The VA-HUD spending bill for the 2005 fiscal year, passed by Congress and signed into law by President Bush last December authorized a 1.9% decrease from fiscal year 2004 in the National Science Foundation (NSF) budget. This cut comes on the heels of Congress' resolution in 2001 to double the NSF budget in five years. As Alan Leshner, the Chief Executive Officer of the American Association for the Advancement of Science (AAAS), pointed out in his December 2004 editorial in *Science*, this decrease is only the third cut in the NSF's over-50 year history. Although the National Institutes of Health (NIH) received an increase of 2% over fiscal year 2004, the competition for grants from the NIH will continue to be, as one program officer put it, "White hot!" since this increase is well below the rate of inflation in the biomedical science arena. Unfortunately for our community, the 2006 budget proposed by the White House is not shaping up to look much better. According to a recent analysis by Kei Koizumi at the AAAS, "In real terms, the total federal R&D portfolio would decline for the first time since 1996."

Despite the immediate bleak economic outlook and the diminished funding in the sciences, science in the United States continues to fuel the imagination of the public and reflects our community's restless search for answers about the nature of the world around us. Americans continue to reap an extraordinary number of Nobel Prizes for their scientific discoveries. Because of our community's dedication to discovery reflected in long days and weeks where work-weekdays flow seamlessly into work-weekends, we have made tremendous leaps in our scientific understanding. We have revealed the nature of the human genome. We have successfully completed missions to Mars and worked with the Europeans in exploring Titan, one of Saturn's moons. We are on the cusp of finding cures for previously incurable diseases that led almost certainly to horrible and painful conclusions to

lives that were once rich in hopes, aspirations, and contributions to family and society.

It is this paradox that brings to mind an old Cuban fable about a pair of twins, Alejandro and Santiago, each of whom suffered from respective cases of extreme pessimism and optimism. Their mother, Señora Garcia, was very concerned that the boys would be unable to function in the world with such extreme outlooks. So she took them to a psychoanalyst who comforted her saying that they were just going through a stage and they would grow out of it within a year. Well, a year came and went, and Alejandro was as pessimistic and Santiago was as optimistic as ever. She finally decided to take them to a therapist who practiced radical behavioral therapy. The therapist informed her that by placing each of the children into a room filled with powerful controlling stimuli, she could guarantee that the boys would abandon their extreme outlooks. Señora Garcia with some trepidation agreed to go through with the procedure. So the therapist placed Alejandro, the pessimist, into a room filled with beautiful toys, of every color, size, and shape. Everything a child would love to have. She then placed Santiago, the optimist, into a room filled with horse manure, a room so vile that any child would find it horrible.

After several hours, Señora Garcia and the therapist went to check on the boys. When they opened the door to the toy room, there was Alejandro, the pessimist, sitting in the middle of the room and sobbing uncontrollably. Señora Garcia asked "Mi cielo, what is the problem?" And the boy looked up at her and the therapist, and cried "With all these beautiful toys here, someone is bound to come and take them all away from me!" The therapist shook her head and concluded that there was no hope for poor Alejandro.

They next went to visit Santiago, the optimist. When they arrived, they could not believe their eyes. Santiago was running through the room, laughing, leaping through the air, and landing headfirst into piles and piles of horse crap! "Dios Mio!" Señora Garcia exclaimed. "What are you doing, Santiago?" Santiago, shaking his head and laughing looked up at his mother and gleefully announced "Well, Mama, with all this horse poopy, I figure there has to be a pony in here somewhere!"

Our community and Santiago share a common trait: OPTIMISM. We are optimistic that our efforts to educate undergraduates in the sciences, to conduct research in predominantly undergraduate institution (PUI) settings, to integrate teaching and research in PUI settings are not only worthy, but of paramount importance to nurture and sustain the technological and intellectual tradition of our

Nation. Our community is hard at work trying to find that pony. For the remainder of this essay, I would like to explore two issues that are particularly important for our science education community to consider: 1) The benefits of integrating teaching and research; 2) A science curriculum that might promote that integration.

Integration of Teaching and Research

The National Science Board's Task Force on National Workforce Policies for Science and Engineering recently published a report that clearly underscores the need to enhance recruitment and retention of students in the sciences and recommends that the Federal Government direct resources "to improve success in science and engineering by American undergraduates from all demographic groups." The Task Force draws attention to the threat that we may not have sufficient numbers of students in the sciences and engineering to meet our Nation's future needs in academia and industry. The Policy Information Center at the Educational Testing Service and the U.S. Bureau of Labor Statistics estimate that by 2010 as many as 21.2 million baby boomers will no longer be in the workforce, resulting in about 2.9 million job vacancies in computer science, engineering, and the physical sciences. As the National Science Board's report states, we have historically relied on the pools of talent available in other nations that we have attracted to the United States to offset possible shortfalls. The competition for this pool of talent, however, is becoming more intense and we may find ourselves unable to attract scientific talent from other nations in sufficient quantity to help fuel the economic and scientific engines of our society. Coupled with the NSF's 2004 report on "Women, Minorities, and Persons With Disabilities," it is apparent that we have also failed to adequately engage significant segments of our society in the scientific enterprise – women, African Americans, Hispanic Americans, and American Indian are severely underrepresented in the sciences and engineering. Clearly, we have work to do.

Despite the wake-up call with the publication of "A Nation at Risk" some 20 years ago, we continue to find our Nation's economic and scientific foundations threatened by structural failings in our system of higher education. Unless we nurture scientific creativity and critical thinking in our educational system, we may not adequately prepare our students for the competitive world they will encounter in the 21st century. Indeed, if we fail to convey the passion of scientific discovery to our Nation's students, we will fail to capitalize on the wealth of potential scientific talent within our borders that will be crucial to enhancing our Nation's competitiveness in the sciences.

Since the publication of a "Nation at Risk," numerous reports have documented America's failure to adequately educate its students in the sciences and mathematics. Our students regularly perform poorly on international assessments of science and mathematics aptitude among industrialized nations. At the end of last year, for example, the Program for International Student Assessment indicated that American teenagers performed worse than two-thirds of the world's industrialized nations in science

and math skills. Because a scientifically literate citizenry is a necessary precondition for successful competition in the global marketplace, America is dangerously close to jeopardizing both its economic stability and its place as global leader in the scientific enterprise.

Fortunately, the National Research Council's (NRC) Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century published a report in 2003 designed to guide the biological education community as to how best prepare students for the future and to bring the excitement of scientific inquiry to our students. Many of the recommendations the Committee made are as salient for the social and physical sciences as they are for the biological sciences.

The NRC Committee points out that a particularly effective method by which students can be introduced to the richness of scientific inquiry is to encourage them to conduct *original scientific research* – emphasizing the breadth of the process: posing the questions, designing experiments, collecting and analyzing data, communicating the findings orally and in writing. As a recent Council on Undergraduate Research (CUR) "White Paper" states, undergraduate research introduces students "to the joys of discovery as well as to lessons in persistence, problem-solving, and critical thinking." The NRC Committee also notes that many researchers were drawn into the life sciences because of a mentor who collaborated with them while they were undergraduate students conducting research. Fostering the development of mentoring expertise among faculty members and providing faculty members with opportunities to mentor students in research settings are critical elements in the national effort to enhance undergraduate science education.

As noted in the NRC Committee report, the body of evidence exploring the educational value of the undergraduate research experience and the impact of this research on faculty development is not particularly abundant. The consensus within the science community, from the physical sciences to the social sciences, is that undergraduate experience with original research is clearly a valuable way to educate the next generation of scientists. The Boyer Commission report in 1998 argued that the integration of research experiences into the education of students attending research universities was of paramount importance. Finally, the NRC Committee in BIO 2010 recommends that "All students should be encouraged to pursue independent research as early as is practical in their education. They should be able to receive academic credit for independent research done in collaboration with faculty and off-campus researchers."

Two organizations in particular, the Faculty for Undergraduate Neuroscience (FUN) and CUR, have championed the integration of teaching and research since their founding. Undergraduate research is viewed by our science education community as a vehicle by which students can be educated in the sciences and by which faculty and their students at PUIs may directly contribute to the expansion of knowledge.

Although this area of education research appears to be in its infancy, evidence now emerging indicates that

undergraduate research experience enhances student retention, positively affects the career choices undergraduate students subsequently make, and may improve the quality of faculty members' lives. Having students engage in a structured research experience (characterized by bibliographic research assignments, formulating research questions, conducting studies and doing research presentations) significantly improves the retention of students in college, particularly African American students. Retrospective studies from the University of Michigan and the University of Delaware found that students with structured research experiences reported greater enhancement of cognitive and personal skills such as speaking effectively, independent acquisition of information, appreciation of important literature in their chosen field of study, leadership ability, critical thinking, understanding scientific findings, conducting research, clarity of career goals, and intellectual curiosity. Notably, these enhancements appear to correspond well with faculty impressions of the benefits derived from undergraduate research experiences. Hathaway and colleagues in 2002 reported finding a strong relationship between undergraduate research experiences and matriculation in graduate/professional school as well as research activity upon graduating with a baccalaureate degree. Students with these experiences also tended to request letters of recommendation from the faculty and to maintain contact with the faculty after graduation. A study by Solomon and colleagues in 2003 on the pursuit of research careers of medical students has some bearing on this issue. Medical students who engaged in intensive summer research experiences were much more likely to pursue research careers subsequent to medical school; in fact, students who participated in the summer research program were twice as likely to become faculty members at medical schools than their classmates without research experience. Finally, faculty members conducting research with undergraduate students reported having "higher gains in quality of life" because they enjoyed influencing talented undergraduates, their graduate student's education benefited from interacting with undergraduates, and the undergraduates made substantive contributions to the faculty member's research program.

A Science Curriculum

How can our society reform the educational system so desperately in need of help? As a response to the threat posed by poor science education, numerous government agencies from the local to the federal level, school systems from across the country, businesses and private foundations partnered to develop creative solutions to overcome the monolithic inertia that paralyzed our educational system. Organizations such as FUN, CUR, and Project Kaleidoscope (PKAL) are part of the armamentarium that we and our colleagues are using to inject new life into the nation's anemic educational infrastructure. Two reports published within the last decade in particular may provide significant guidance as we attempt to improve science education in the United States: *The National Education Standards*, published by

the National Research Council and aimed at grades K-12; and *The National Science Foundation's Review of Undergraduate Science, Mathematics, Engineering, and Technology Education*. These two reports provide direction that stretches from elementary school through college. To summarize three major tenets of these reports, a science education should prepare Americans: 1) to engage fully in the national debate focused on issues grounded in scientific issues; 2) to be capable of weighing evidence and make informed decisions in their personal lives; and 3) to have the requisite skills to succeed in technological industries.

With the national agenda for science education clearly outlined, we may now ask how our community can help our Nation attain those goals. The solutions will likely be multi-pronged and as varied as the school systems across the nation. There are, however, threads that may bind these approaches into a coherent framework.

The Overarching Objectives of a Science Education

A number of commonalities among recent science education proposals meant to guide curricular development may serve as objectives that should be considered as science educators develop science programs best-suited to their specific environments. The educational objectives emphasize laboratory-rich experiences and an inquiry-based academic curriculum that integrates teaching and research. Because the resources that institutions have access to vary greatly, it is recommended that institutions play to their strengths as they develop their science curricula, while adhering to a strong pedagogical and scientific foundation.

The ultimate goal of a scientific education is to help our students develop a scientific "attitude." As students move from their first to their senior year, we should place increasing emphasis on having students read and critically assess the primary literature, design and analyze experiments that may yield novel findings, and develop more sophisticated laboratory skills. By their senior year, undergraduate students should be able to articulate how the various disciplines contributing to their field of interest work together to address issues of fundamental importance to science and society, the big picture. Accordingly, in the senior year a capstone experience, such as a research project, thesis, or special topics seminar, would promote critical and integrative thinking.

As quoted and modified from "Undergraduate Education in the Neurosciences: Four Blueprints" by Ramirez and colleagues in the 1998 PKAL publication *Occasional Paper in Neuroscience*, the principal objectives of an undergraduate education in the sciences include:

1. Promoting critical and integrative thinking.

Students need to learn the cornerstone of the scientific enterprise – thinking critically about the phenomena they are being introduced to, about the arguments and principles they are studying, about the relationships among hypotheses, methods employed in scientific investigations, and the consequent interpretations of the data. Students

should be introduced to the notion that different levels of analysis which often cross disciplinary borders can inform our efforts to understand natural phenomena.

2. Promoting communication skills orally and in writing.

Students are often under the mistaken impression that scientists conduct their work in laboratories in the bowels of science buildings and rarely interact with other human beings. Of course, Hollywood hasn't helped us a whole lot to dispel that image. Therefore, we must make every effort to engage students in writing projects and in making oral presentations of their projects at every level of their education. It is also important to encourage them to discuss scientific issues among themselves as well as with their instructors. To the dismay of some of our colleagues, they may learn more from one another than they do from us!

3. Illustrating the interdependent nature of the sciences.

A broad background in the sciences (from the social sciences, the life sciences, and the physical sciences) as well as experience in the humanities would best prepare students to engage in the national dialogue so important to ensure the future well-being of our Nation. Although the courses can be tailored to the students' specific interests in the sciences, a broad exposure to the sciences will not only prepare them for the study of their chosen passion but will reinforce the notion that the sciences are indeed interconnected.

4. Imparting an understanding of the resources and limitations of the scientific enterprise as regards our society's biomedical, economic, environmental, and ethical challenges.

It is probably still safe to say that most citizens recognize the importance of the biomedical sciences for defeating the illnesses that are responsible for devastating the emotional and financial lives of families across the country. Unfortunately, it is also clear that many do not quite recognize the complexity of investigative work or the importance of basic research across the sciences. For example, many citizens are at a loss as to how science is conducted, what are reasonable expectations with respect to the pace at which scientific research proceeds, what constitutes a valid scientific approach. As a democratic society, our citizens are key to the health and well-being of the scientific enterprise. It is incumbent upon the scientific establishment to educate them and welcome them into our scientific home.

CONCLUSION

In some arenas of Academe, you will encounter colleagues and administrators who view teaching and research as incompatible enterprises. "Surely, if you do one well, it must be at the expense of the other!" they'll bellow with utter certainty. Over twenty years ago, when I made the decision to pursue a career in which I would have the delight and privilege of educating undergraduate students, of introducing young minds to the wonder and

beauty of the nervous system, I never viewed that career path as being mutually exclusive with research.

Teaching and research are inextricably linked vocations – one informing and energizing the other. This dynamic exchange enables professors to more readily inspire, encourage and empower their students – the essence of teaching. Maintaining an active research program grounds teaching scholars in the passion of inquiry and it compels us to remain current in scientific research being published in our scientific specialty. Our passion for discovery, which is based on our current understanding of scientific principles and phenomena, energizes what we have to say in the classroom or in the laboratory so that we can **inspire** our students to seek answers to their own questions. Teachers who aren't actively engaged in research may be most certainly passionate about what they teach and are most certainly capable of remaining current, but having research questions constantly bubbling in our minds keeps us in close contact with current scientific publications and with research colleagues at other institutions. In addition, having one's work assessed in the peer-review process, whether as publications or grant applications, has a *healthily humbling* impact on a teaching scholar. Putting our work out on the national stage for critique heightens our sensitivity to the trepidation that a student may experience when writing a paper in one of our courses or to the bruises students' egos may encounter when we return their work. Because we're actively engaged in research, our experiences are not so far removed from our students' experiences. The sense of empathy we gain from these experiences can translate into a commitment to support and to **encourage** our students when they flounder. By engaging students as full partners in our scientific work, we confirm that they have the wherewithal to undertake complex and important work, that they can learn and synthesize tremendous amounts of information, and that they can articulate these new ideas in clear terms to others. Simply put, we prepare and **empower** them for their own future explorations into the workings of the natural world.

On the flip side, teaching energizes our research activity by keeping teaching scholars engaged with lively and enthusiastic students fervently throwing themselves at fundamental questions in the sciences. Their excitement is infectious and stimulates our research discussions. Students raise questions and provide insights in class or in the lab that can trigger additional avenues for us to pursue in our research efforts. Thus, teaching itself may provide a forum from which to generate interesting research questions. On a more practical side, formulating ways to talk about science with an undergraduate audience, to help them understand the importance of scientific research, to help them appreciate scientific observations and principles, hones our skills to relate our research to scientific audiences as well as to the lay public.

Faculty attempting to integrate teaching and research in some PUI environments may encounter obstacles from other colleagues and an administration who fear that a faculty member's research may undermine the educational

experience of undergraduate students. The challenge will be to persuade these colleagues and administrators that educating a scientist is tantamount to educating a musician. How can we expect a music major to develop into an accomplished pianist without ever having touched a piano? Similarly, how can we expect an undergraduate science major to develop into a proficient scientist without ever having conducted original scientific research? The development of intellectual skills required to conduct research as a scientist will only serve to enhance the educational experience of undergraduate science students and will ultimately best serve the needs of the Nation.

If you encounter resistance to your efforts to integrate teaching and research at your home institutions, if the tone of the national debate on research and education leaves you a little less than invigorated in your efforts to educate your students, take a deep breath and remind yourselves that you have dedicated your lives to a noble profession. The future of our Nation depends on the good work that you are doing with your students in the classroom, in the laboratory, or in the field. During those moments when you seem to be fighting an uphill battle remember little Santiago and exclaim "There's a pony in here somewhere!"

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