Research and Discovery Across the Curriculum

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The national conversation on undergraduate research is gaining momentum, in part because of its identification as one of the ten high-impact educational practices identified in an analysis of data from the National Survey of Student Engagement (NSSE), published by the Association of American Colleges and Universities (Kuh 2008). However, the trend is not new; the Council on Undergraduate Research (CUR) has been a leading proponent of undergraduate research for the past thirty years. According to CUR, undergraduate research is "an inquiry or investigation conducted by an undergraduate student that makes an original intellectual or creative contribution to the discipline." Ramirez and Hoagland (2003) state that faculty and students should be encouraged to collaborate as partners in their explorations of uncharted intellectual terrain. The symbiosis established between the faculty member and undergraduate collaborator energizes and informs the faculty member's teaching and research while simultaneously introducing the student to the joys of discovery as well as to lessons in persistence, problem-solving and critical thinking.

Thus, it is as much a matter of effective teaching and learning as it is a matter of research and scholarship. In STEM (science, technology, engineering, and mathematics) disciplines, Project Kaleidoscope, working over the past twenty years to advance effective STEM education, has also played a role. The National Science Foundation's Research Experience for Undergraduates (REU) and Research in Undergraduate Institutions (RUI) programs and various scientific societies have also helped to promote, support, and highlight the work of undergraduate researchers. Many funding agencies, philanthropic foundations and other organizations have also touted and supported the educational benefits of undergraduate research across all disciplines for decades, including the National Humanities Alliance, which holds an annual Humanities Advocacy Day. Undergraduate research experiences are also held in high regard by faculty members: more than 50 percent of faculty members reported on the Faculty Survey of Student Engagement (FSSE) that participation in a research project with a faculty member is important for students (National Survey of Student Engagement 2008). Students in all disciplines are also increasingly calling for such experiences (Society of Physics Students 2008). In this article, we provide an analysis of the value of undergraduate research and suggest that its essence be used to infuse a pedagogy of research and discovery into courses across the curriculum for a more relevant, real-world, research-rich educational experience.

WHAT MAKES UNDERGRADUATE RESEARCH VALUABLE?
Undergraduate research is associated with a wide range of positive benefits for students. A series of studies summarized on the CUR Web site highlights the critical role undergraduate research plays in advancing student learning (Kardash 2000; Lopatto 2003; Seymour et al. 2004), in increasing the likelihood of earning a degree, and specifically in retaining diverse students in fields in which they are historically underrepresented (Nagda et al. 1998), and in increasing students' pursuit of advanced education (Bauer and Bennett 2003; Hathaway, Nagda, and Gergerman 2002; Kremer and Bringle 1990). These studies bolster the assertion in the Boyer Commission on Educating Undergraduates in the Research University report (1998), which emphasized the benefits
of inquiry-based learning experiences and the recommendation that a supervised research project be incorporated into the undergraduate program.

Recent reports using data from the National Survey of Student Engagement (NSSE) and assessment studies, such as those led by Elaine Seymour and David Lopatto, reinforce findings of the educational value of undergraduate research and focus attention on the importance of assessing the nature and quality of undergraduate research experiences. These projects also provide an opportunity to distinguish the features that make undergraduate research so effective. NSSE results featured in the AAC&U publication High-Impact Educational Practices (Kuh 2008) were used to explore the effects of six high-impact activities, including undergraduate research, on first-year and senior student self-reported gains in three clusters of learning and personal development outcomes, and in engaging in deep approaches to learning. Results showed positive associations between high-impact activities and all gains and deep approaches to learning. In addition, students who have these experiences are also more engaged overall in the NSSE clusters of effective educational practice. Although it’s likely that certain specific features of high-impact practices exert a significant influence on learning gains, it is notable that these practices are effective because they are clearly marked by six hallmarks of high-impact practices that put students in circumstances that demand meaningful faculty and peer interaction; help students connect their learning to real-world settings; occur in the context of a coherent and challenging curriculum; provide students with frequent feedback; require time on task; and challenge students to think in new ways and respond to novel situations. Moreover, they suggest the features that should be carefully crafted into undergraduate research experiences.

Additional features of undergraduate research and what students gain from the experience were explored more fully via a set of NSSE items. Results based on 2,674 students from a variety of major fields at sixty-three baccalaureate institutions showed that doing research with faculty was positively associated with deep approaches to learning and gains in general education, personal and social development, and practical competencies (NSSE 2007). Students reported a range of contributions to the research project, including designing the study, reviewing literature, collecting data, and presenting findings. Although most of these practices were positively related to educational gains, the activities with the strongest association were reviewing literature and interpreting findings. The advantage of doing research with a faculty member is that students are able to spend time in the company of a professional researcher and learn firsthand how he or she thinks and deals with the challenges of research. Also, these interactions make students more likely to receive feedback during or after their project and to report more supportive relationships with faculty members. Finally, the more time students spent on the research project, the better they came to understand the inquiry process and the more they gained overall.

ESSENTIAL FEATURES OF UNDERGRADUATE RESEARCH

Lopatto (2003) reports several essential features of undergraduate research, as identified by faculty members. These encompass reading the literature, designing some aspect of the project, feeling ownership of the project with an increasing independence over time, using careful and reproducible lab techniques (and even mastering some), striving to produce a significant finding, and presenting results in both oral and written communication formats. In Science in Solution (2009), Lopatto writes

Undergraduate research, done well, engages multiple dimensions of a student’s cognitive, behavioral, and attitudinal skills. Task-specific learning about instruments and methods cascades into active hypothesizing and procedural troubleshooting that result in the accumulation of self-confidence and independence that help shape the student’s vision of her future. The whirlpool of outcomes mixes value added with value expressed, that is, mixes the guided...
acquisition of expertise with the discarding of the fear of expressing ideas and hypotheses.

As this eloquent passage suggests, undergraduate research experiences benefit students in ways that transcend mastering disciplinary knowledge or helping students obtain a more professional orientation (Lopatto writes more about this later in this issue). Many of the benefits of undergraduate research are aligned with three of the essential learning outcomes espoused by AAC&U's LEAP campaign—intellectual and practical skills, personal and social responsibility, and integrative and applied learning. It is these kinds of experiences that have the potential to transform the way students perceive and understand what they are learning and how it is applied in authentic, real-world situations.

Besides contributing to an individual student’s professional development, undergraduate research can and should also result in contributions to the discipline or to community or to solving even larger societal problems. While the contributions to a discipline by any single student might be small, they contribute to a larger body of collaborative work done by other students and a faculty mentor over time. Some undergraduate research projects can be categorized as transformative—a term defined by the National Science Board (NSF 2007) as research driven by ideas that have the potential to radically change our understanding of an important existing concept or leading to the creation of a new paradigm. Over the past year, CUR engaged in a study of transformative research that was recently published (Karukstis and Hensel 2010). Many examples of undergraduates participating in transformative research were found, such as students at the University of Central Florida and Davidson College collaborating with industry to develop or screen new chemicals for agriculture and medicine.

Undergraduate student participation in research is now also seen by many as a way of developing leaders for the twenty-first century. By presenting their research to campuswide audiences, to peers at national conferences such as the National Conferences on Undergraduate Research (NCUR), to scientists at disciplinary society meetings, and to legislators at the state and national level, students learn to communicate at a variety of levels—including to “non-expert” audiences (in terms of scientific literacy). More institutions are providing avenues on campus to showcase students’ creative work. In 2010, Grand Valley State University hosted its fifteenth annual Student Scholar Day to celebrate the faculty-mentored student research and creative work presented by more than six hundred students. And the University of Maine–Farmington sponsored its fifth symposium, a university-wide day of presentations of outstanding student scholarship and creative achievements across academic disciplines. These events also attract members of the surrounding communities. Because a growing number of undergraduate research projects have significance to the local community, events like these increase the chances for researchers to interact directly with the public and use the projects as an opportunity to educate a general audience about science. Besides enhancing students’ communication skills, all of these dissemination activities also enhance public understanding of science and allow our students to become ambassadors for illustrating the importance of science and research in society.

PKAL and CUR have long advocated for making research-rich experiences available to students early in the curriculum, integrating inquiry and analysis into coursework, and giving students the chance to use problem-based learning to apply their knowledge, to use case studies of scientific data, and to collect primary data in the field or as part of a larger research collective. For example, Cleveland State University’s undergraduate research learning community (described later in this issue) provides first-year students in any major the opportunity to work on their own original research, develop a faculty-guided proposal, and conclude the semester with a presentation. The courses provide the framework for the creative research activity, but it’s the interaction with faculty that provides new students with active, inquiry-based learning experiences with a faculty mentor. And at Grinnell College, the biology department has “inverted” the curriculum so that first-year students with interests that span the disciplines engage in “doing science” right away, as opposed to saving the excitement of real investigation for upper-division biology majors (Lindgren 2010). Lindgren notes that teaching in this way is “painfully authentic,” meaning that students discover that experiments don’t always work or yield clear results, as often shown in their...
textbooks. But, perhaps teaching real science requires us to take a kind of “tough love” approach in order to help students understand the true nature of science, including its limitations. Russell, Hancock, and McCullough (2007) argue for earlier involvement in research for students in STEM disciplines, based on their study of the educational benefits of research and its influence on STEM career choice.

INFUSING A PEDAGOGY OF RESEARCH AND DISCOVERY ACROSS THE CURRICULUM

While the ideal undergraduate research experience is one in which students work closely with faculty members on a high-quality, original research project, high costs and personnel limitations make it difficult to provide the ideal mentored experience to all students. However, by understanding the essence of what makes undergraduate research such a valuable experience and then applying these principles more widely in courses and programs across the curriculum, we can provide opportunities for more undergraduates to experience similar benefits. Expanding meaningful research experiences to more students is particularly relevant in the face of increasingly frequent conversations about the need for a citizenry that can engage in evidence-based reasoning to deal with this century’s complex and global challenges—such as climate change, energy use, water resources, and world health—that involve multidisciplinary perspectives. All students should have a personal experience with the complexity and interrelatedness of the issues facing our global society in order to be competent consumers, communicators, decision makers, teachers (see article by Baker and Keller later in this issue), and professionals in this new global century.

A number of grand challenges in engineering, the environment, and global health have been identified (National Academy of Engineers 2009; National Research Council 2001; Bill and Melinda Gates Foundation 2008). These range from the need to develop a better understanding of biological diversity, ecosystem functioning, climate variability, and hydrologic forecasting; to finding renewable, clean energy solutions or “greener” materials that lessen our dependence on diminishing natural resources; to global health issues including the development of new vaccines or novel ways to control infectious disease. A recent report from the National Research Council (2009) entitled, “A New Biology for the 21st Century,” responded to the following question: How can a fundamental understanding of living systems reduce uncertainty about the future of life on earth, improve human health and welfare, and lead to the wise stewardship of our planet? The report findings assert that the new biology must be more integrative—not only across the field of biology, but across other disciplines—if we are to take full advantage of the power of science to address the complex societal problems we face. Key global research issues identified in this report are those surrounding health, the environment, energy and water. The United Nations Millennium Development Goals (such as ending hunger, improving maternal and child health, combating HIV/AIDS, and environmental sustainability) will also require great advances from the scientific community working closely with our colleagues in the arts and humanities. These reports, as well as others that address the sciences more broadly, suggest an increasing convergence leading undergraduate education in more interdisciplinary and integrative directions (Labov, Reid, and Yamamoto 2010). All types of perspectives, talents, and skills will be required.

Applying evidence-based reasoning to solve complex societal problems is certainly not a new educational goal, but what is new is the urgency with which some of these problems need attention. Lessons from studies about what makes undergraduate research effective provide a fresh perspective for considering a twenty-first-century framework for a pedagogy of discovery, inquiry, and analysis in undergraduate education. The research highlighted in this paper suggests that these opportunities must be designed to:

- Challenge students to confront novel ideas
- Engage students in the collection and analysis of original data
- Emphasize opportunities for applying research to real contexts or solving real problems
- Increase the time students dedicate to the project
- Maximize opportunities for students and faculty to interact and engage in substantive matters
- Be relevant and interesting to students, and influenced by their ideas to maximize engagement and learning
- Provide opportunities for students to receive frequent and meaningful feedback about their work
- Increase students ownership of the project over time
- Provide an occasion for students to present their work in oral and written formats
- Allow students to work in teams

A number of colleges engage students in research related to environmentally contaminated industrial sites in their neighborhoods. This work is often interdisciplinary and integrated with coursework, but students are also performing important monitoring studies, examining the flow of contaminants through water systems or food chains, and developing management protocols to minimize public health and environmental risks. At Moravian College, students are involved in a Superfund site revitalization project that has received national recognition for its success in turning a heavily contaminated
moonscape into a thriving grassland and wildlife refuge. Besides conducting a range of scientific studies, students are engaged with state and federal agencies in developing adaptive management protocols for the site. One student’s project led to the creation of a searchable annotated bibliography with close to five hundred different references, including federal reports, abstracts, journal articles, books, theses, Web sites, fact sheets, magazines, newspaper articles, PowerPoint presentations, letters, videos, maps, photographs, and more, which was used by researchers, the EPA, the regional library (which houses many of the public documents and historical materials from the zinc smelter company responsible for both creating the town and the Superfund site) and the general public.

EDUCATION THAT TRANSCENDS THE CLASSROOM

Over the past year, there have been a number of editorials that have rehashed the false dichotomy between teaching and research, claiming that faculty (especially those working with undergraduate students) should focus on teaching so as not to “lose sight of the educational mission” (Jones 2010). However, our educational missions involve more than teaching in traditional classroom settings. Learning occurs in a variety of situations, both inside and outside the classroom, and in a variety of ways, as the High-Impact Educational Practices report (Kuh 2008) highlights. Education in the twenty-first century must have a view that transcends the classroom and engages students in the grand challenges and complex problems facing our society, and what better way to do this than to involve them in the pursuit of a relevant, real-world problem? A white paper published by the Teagle Foundation Working Group on the Teacher–Scholar (2007) provides a concise argument for the robust connections and synergy between teaching and scholarship at both undergraduate institutions and research universities. Fully embracing a pedagogy of discovery, inquiry, and analysis suggests integration of teaching with research as opposed to separation. Certainly financial considerations must be taken into account, but already many institutions are succeeding and there are many examples across the institutional spectrum of models that incorporate research-rich experiences into courses across the curriculum to engage more students in the core aspects of this high-impact practice. Campus leadership will be required to foster a continued vision for engaging students in undergraduate research experiences and research-rich courses in these challenging economic times and beyond. But for the future of our world, it will be worth the effort.

REFERENCES


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