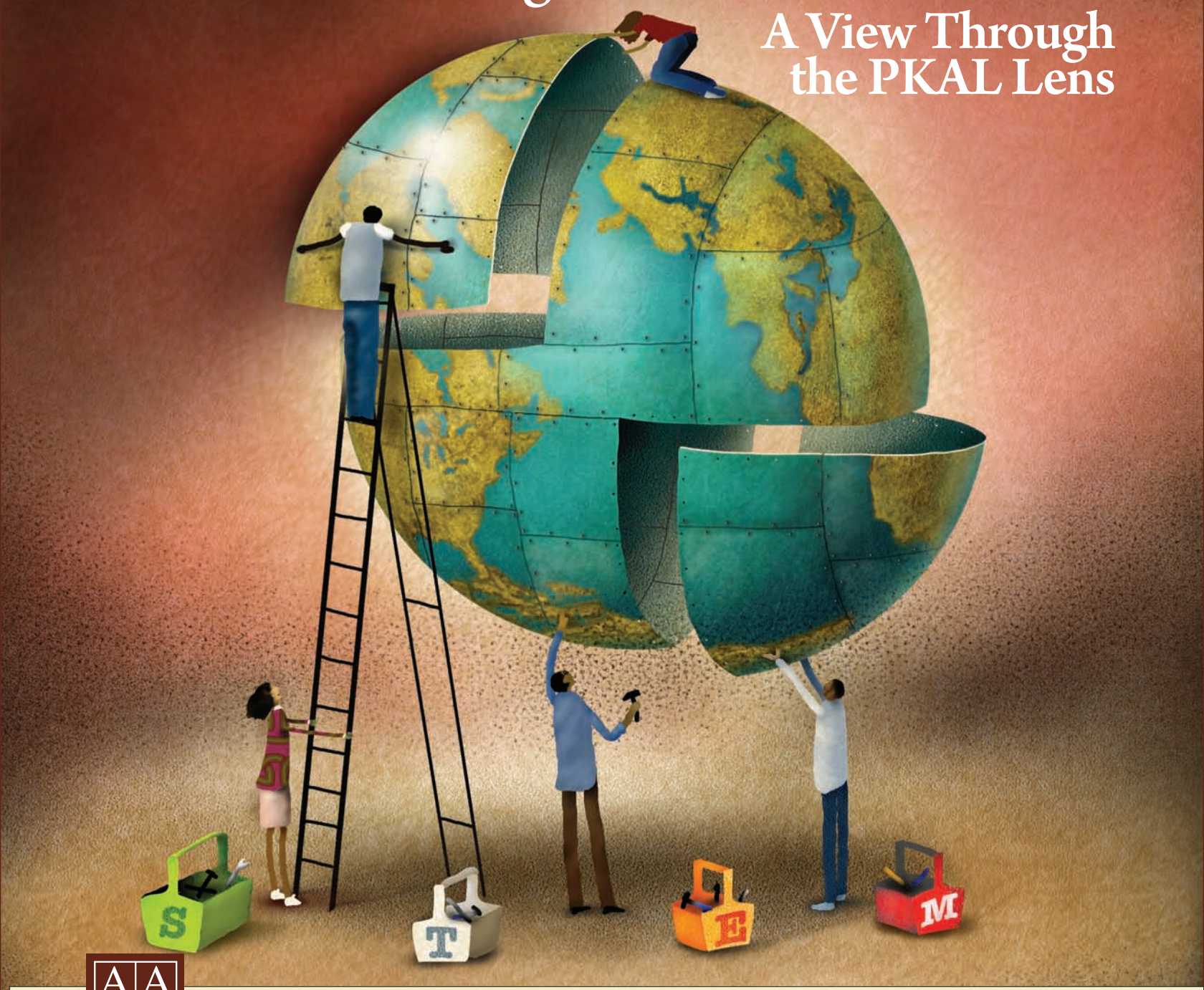
VOL. 13, NO. 3 | SUMMER 2011

peerReview

EMERGING TRENDS AND KEY DEBATES IN UNDERGRADUATE EDUCATION

Advancing What Works in STEM: A View Through the PKAL Lens



A PUBLICATION OF THE ASSOCIATION OF AMERICAN COLLEGES AND UNIVERSITIES

CONTENTS

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Published by the Association of American Colleges and Universities ©2011
1818 R Street, NW • Washington, DC 20009
202.387.3760 • www.aacu.org

ISSN: 1541-1389

SUMMER 2011

From the Guest Editor
Susan Elrod, PKAL/AAC&U 3

ANALYSIS

STEM Education: Time for Integration
Susan Rundell Singer, Carleton College 4

PRACTICE

Transforming Science Education through Peer-Led Team Learning
Thom D. Chesney, Brookhaven College 8

Creating Interdisiplinary Science Programs: Purposes, Progress, Potholes
Whitney M. Schlegel, Indiana University Bloomington 11

Twenty-First-Century Quantitative Education: Beyond Content
Shannon W. Dingman and Bernard L. Madison, both of the University of Arkansas . . 15

Interdisciplinary Problem-Solving to Advance STEM Success for All Students
Reneta D. Lansiquot, Reginald A. Blake, Janet Liou-Mark, and A. E. Dreyfuss; all of New York City College of Technology, CUNY 19

RESEARCH

STEM/ Non-STEM Differences in Engagement at US Institutions
Thomas F. Nelson Laird, Indiana University, Bloomington: Daniel F. Sullivan, St. Lawrence University; Christine Zimmerman, St. Lawrence University; and Alexander C. McCormick, National Student Survey of Engagement and Indiana University, Bloomington 23

Using Research to Bring Interactive Learning Strategies into General Education Mega-Courses
Edward Prather, University of Arizona; Alexander Rudolph, Cal Poly Pomona; and Gina Brissenden, University of Arizona 27

REALITY CHECK

Reflections on the Potential Impacts of Reports on STEM Reform
Jeanne L. Narum, PKAL 31

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Peer Review (ISSN-1389) is published quarterly by the Association of American Colleges and Universities, 1818 R Street, NW, Washington, DC 20009-1604. Annual rates are $35 for individual subscriber and $45 for libraries. Periodicals postage paid at Washington, DC and at additional mailing offices. POSTMASTER: Send address changes to: *Peer Review*, 1818 R Street, /NW, Washington, DC 20009-1604.

FROM THE GUEST EDITOR

With a new wave of national reports and recommendations regarding STEM (science, technology, engineering, and mathematics) education recently hitting the Internet, we are again reminded of the imperative to improve student learning and success in these fields. Whether addressing the lagging graduation rates for students from underrepresented groups or advancing scientific and quantitative literacy for more students in general education courses, as educators we are faced with the imperative to improve student learning and success in STEM fields of study.

This issue of *Peer Review* emerges from the new partnership between Project Kaleidoscope (PKAL) and the Association of American Colleges and Universities and provides a critical lens on current trends and emerging practices in STEM education. Recent reports from the National Academies focus particularly on the need for greater alignment between high school and college curriculum and between community college and four-year college STEM introductory programs as well. Many campuses have been making progress in improving STEM learning. This issue of *Peer Review* highlights this progress. You will see that there is evidence of progress but also with recognition that broad implementation of STEM reforms has been slow in coming.

Followers of the STEM reform movement will recognize in these articles the continuing emphasis on interactive and engaging pedagogies, of which PKAL has been a staunch advocate for over two decades. These practices improve student learning, even in large lecture classes, but also motivate students to persist in STEM courses. In addition, we focus on quantitative reasoning and interdisciplinary learning. Arguably, both of these are critical skills for twenty-first-century student success, and both require intentional cross-departmental vision and coordination. This is often easier said than done. The articles on interdisciplinary learning are from participants in PKAL's Facilitating Interdisciplinary Learning project and they highlight successful programs and processes for making these kinds of learning environments for both students and faculty work more deliberately and sustainably.

An analysis of National Survey of Student Engagement (NSSE) data takes a closer look at STEM student engagement compared to non-STEM majors. A startling result of this analysis shows that STEM students appear to be less engaged in pedagogies that encourage higher-order, integrative, and reflective learning than their non-STEM counterparts; however, engagement in active and collaborative learning and positive student–faculty interaction on the part of STEM majors are on par with non-STEM majors. These mixed results are particularly discouraging because many faculty members, campus leaders, scientific societies, and national organizations—including Project Kaleidoscope—have been focusing on just these kinds of changes for decades. Clearly many campuses have made changes in their STEM learning environments, but this national analysis suggests we have a long way yet to go to ensure that all students are having the kinds of high-impact experiences we know promote the highest levels of student learning and success.

We can no longer wait for another Sputnik moment. The time is now and we know what to do. Campus leaders should waste no time gathering data on student learning and success in STEM and formulating systemic plans to set a course that ensures all students succeed in gaining the quantitative and scientific understanding required for life and work in this century. We hope this issue provides both inspiration and motivation for accelerated campus action. **—SUSAN ELROD**

In January 2010, Project Kaleidoscope (PKAL) formally partnered with the Association of American Colleges and Universities (AAC&U), in order to continue and expand PKAL's work in advancing "what works" in undergraduate science, technology, engineering, and mathematics (STEM) education. The partnership between PKAL and AAC&U greatly benefits both communities, because science and mathematics are central to liberal education in the twenty-first century. AAC&U's Liberal Education and America's Promise (LEAP) initiative emphasizes the importance of mathematics and the sciences, as well as their application through technology and engineering. Since its founding in 1989, PKAL has been a forceful influence for shaping new educational pathways into science and mathematics that involve students extensively in "doing science as science is done" by leading an ambitious strategic agenda of undergraduate projects and programs related to (STEM) educational reforms. With an extensive network of nearly 7,000 faculty members and administrators at more than 1,000 colleges, universities, and organizations, PKAL has developed far-reaching influence in shaping undergraduate STEM learning environments that attract and retain undergraduate students.

STEM Education:
Time for Integration

▸ **Susan Rundell Singer,** Lawrence McKinley Gould Professor of Natural Sciences, Carleton College

STEM is more than shorthand for a collection of science, technology, engineering, and mathematics fields, and therein lies the promise of this domain for twenty-first-century education. Boundaries between STEM disciplines are blurring as students and practitioners seek to understand the natural and designed worlds. Our students come to us at an incredibly exciting time as secrets of the Neanderthal genome are unlocked, synthetic life is constructed, the first quantum machine debuts, distant planets are explored, and climate change challenges us to find creative solutions.

The potential of interdisciplinary work across STEM fields is captured in *A New Biology for the 21st Century* (NRC 2009a). Although the report focuses on biology, parallels can be drawn in other STEM fields. Integration of the physical sciences, computer science, biology, engineering, science education, and mathematics is viewed as foundational for a deeper understanding of biological systems. These inputs lead to science-based solutions to societal problems, including in the areas of health, environment, energy, and food, which then inform further research (NRC 2009b). *The Engineer of 2020* report calls for "an engineering profession that will rapidly embrace the potentialities offered by creativity, invention, and cross-disciplinary fertilization to create and accommodate new fields of endeavor, including those that require openness to interdisciplinary efforts with non-engineering disciplines" (NRC 2004, 50).

Preparing students to work at the interfaces calls for a new way of contemplating STEM education. As *A New Biology for the 21st Century* notes, "The New Biologist is not a scientist who knows a little about all disciplines, but a scientist with a deep knowledge in one discipline and a basic 'fluency' in several" (NRC 2009a, 20). Thus the challenge is to provide undergraduates with an education deeply rooted in their chosen STEM field and situated in a broader interdisciplinary context. Project Kaleidoscope's *What Works in Facilitating Interdisciplinary Learning in Science and Mathematics* summarizes a three-year, twenty-eight institution exploration and implementation of interdisciplinary STEM learning, offering strategies for leadership, learning, and campus culture to support interdisciplinary learning at the undergraduate level (PKAL 2011). Quality STEM learning and literacy are goals for all students and increasingly non-STEM jobs require some element of STEM capability.

Whether a new integrated STEM education will enhance student participation in science is an open question. Higher Education Research Institute (HERI) data reveal that underrepresented minorities' aspirations to an undergraduate STEM major are comparable to white and Asian students, yet completion rates are substantially lower (NRC 2010a, 46). While 24.5 and 32.4 percent of white and Asian students, respectively, who started college in 2004 completed a STEM major in four years, only 15.9, 13.2, and 14.0 percent of Latino, black, and Native American students, respectively, who enrolled as STEM students completed a STEM degree in the same time period. Overall there is increasing participation of women in STEM fields, although computer science has actually seen a decrease in female graduates in recent years. And, it's not only the underrepresented groups that we are failing to successfully engage in STEM at the undergraduate level. Overall completion rates for white and Asian students in STEM are substantially lower than in non-STEM fields.

A generation of Americans has passed through K–16 since the publication of *A Nation at Risk*, but a twenty-first-century workforce, high-quality STEM teachers, and a STEM-literate public are still elusive (National Commission on Excellence in Education 1983). Clarion calls for STEM education reform have drawn attention and action in more recent years. Yet, *Rising Above the Gathering Storm, Revisited* (NRC 2010b), found that despite a five-year effort by the public and private sector to implement the committee's

original recommendations, America's competitive position has deteriorated further and there have been few gains in mathematics and science in K–12. Educate to innovate is the new mantra, echoed in the National Science Board's *Preparing the Next Generation of STEM Innovators* (2010) with numerous recommendations for K–12 science education, including differentiated instruction and accelerated coursework, as well as rigorous STEM teacher preparation. The President's Council of Advisors on Science and Technology released *Prepare and Inspire: K–12 Education in Science, Technology, Engineering, and Math (STEM) for America's Future*, a visionary document on ways to enhance K–12 STEM education, and is preparing a report on postsecondary STEM education focusing on the transition to college and the first two undergraduate years (PCAST 2010).

While the pipeline for STEM professionals leaks in many places, it is clear that the end of high school and beginning of college is a critical juncture. It is essential to consider both the culmination of the high school years and the start of college, as well as the critical role of community colleges. Encouraging responses to the lack of alignment of precollege and college experiences include the Science College Board Standards for College Success (CBSCS-S), focused on college and workplace readiness. *Exploring the Intersection of Science Education and 21st Century Skills* aligns with those elements in the CBSCS-S and calls out adaptability, complex communication/social skills, non-routine problem solving, self-management/self-development, and systems thinking (College Board 2009, 3; NRC 2010). Like the CBSCS-S, the Common Core Math Standards focus on college and work readiness. Overall, some coherency in learning goals is emerging from a range of STEM communities at both the college and precollege levels.

CONVERGING ON SHARED STEM LEARNING GOALS

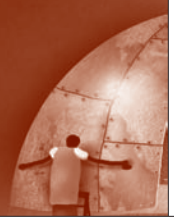
At the broadest level, a set of essential learning outcomes developed as part of AAC&U's Liberal Education and America's Promise (LEAP) initiative, are shared across the STEM disciplines. These become contextualized when situated within disciplinary core concepts and science practice or process skills. Scientific understanding and knowledge are growing at an unprecedented rate and a substantial barrier to effective science learning is mile-wide and inch-deep coverage in curricula, without attention to unifying principles. Critiques of the older Advanced Placement (AP) curriculum underscore the emphasis on broad coverage and insufficient cognitive challenge, while the evidence points to the effectiveness of focusing on a few core concepts and integrating learning about science concepts and practice (NRC 2002, 2007). Intertwined strands of learning were first introduced in the context of mathematics learning and later emphasized in the new *Common Core Mathematics Standards* (NRC 2001). *America's Lab Report* also found strong evidence for interweaving content and process in integrated instructional units where laboratory learning is integrated into the flow of instruction (NRC 2005). Integrated instructional units are at the core of the recommended design principles for laboratory learning which were integrated into the National Science Teachers Association laboratory guidelines and have been implemented at both the precollege and college levels.

The *Conceptual Framework for New Science Education Standards*, developed by the National Academies Board on Science Education, informs a full set of internationally benchmarked standards (2011a). The report reflects a commitment to key, core concepts and the importance of science practice—a substantive shift away from lengthy lists of facts.

Agreement upon the most fundamental concepts and practices may provide greater curricular coherence. For example, in biology the four big ideas in the revised AP curriculum are parallel in content to the five core concepts for biological literacy for undergraduates as outlined in *Vision and Change in Undergraduate Biology Education* (AAAS 2011). Similar alignment is found with the science practices in both. Scientific Foundations for Future Physicians(SFFP) establishes competencies relevant to both concepts and science practice for premedical and medical students (AAMC 2009). At the undergraduate level, these competencies align with and expand upon the *Vision and Change* core concepts and practices, replacing the prior notion of course taking versus competencies.

The integrated nature of STEM is reflected in the shared core concepts for biology students. The physical sciences and mathematics are deliberately included. The importance of modeling is called out in *Vision and Change* and SFFP, and included in the Common Core Mathematics Standards at the high school level. The SFFP competencies are largely interdisciplinary and offer a starting point for cross-disciplinary conversations that may benefit a larger population than the targeted premedical population.

At the undergraduate level, learning goals within a STEM discipline reflect the deep disciplinary understanding required of students, as well as cross-cutting goals within and beyond STEM. Clear articulation of goals has multiple benefits. Colorado University's Department of Molecular, Cellular, and Developmental Biology applied learning goals at the level of courses, reducing redundancy to maximize students' progression through the major. As part of a PKAL regional network, fourteen colleges and universities in the Portland PKAL network (PortPKAL) are collectively exploring reforming their intro-



ductory science courses using the SFFP competencies. ABET, the engineering accrediting agency, has eleven learning outcomes for all engineering students ranging from applying mathematics, science, and engineering knowledge to understanding ethical responsibility. ABET outcomes are aligned with workforce needs. And, across the STEM disciplines, learning outcomes are a first step towards asking whether or not an approach is working. A further push to align learning goals with assessment approaches comes from higher education accrediting agencies.

PROMISING PRACTICES IN STEM EDUCATION

In the interstices between goals and assessments live curriculum, program development, and implementation. While beginning with clear learning outcomes in mind is good practice, getting to the desired outcomes is a distinct challenge (NRC 2011b). A growing body of evidence for effective pedagogies comes from the emerging field of discipline-based education research (DBER), with a study on the state of the research and the field in process at the NRC. DBER researchers use both their deep disciplinary expertise and education research tools to understand how to support student learning. Detailed reviews of the state of astronomy, biology, chemistry, engineering, geoscience, and physics education research are available at http://www7.nationalacademies.org/bose/DBER_Homepage.html.

Engaged learners are at the core of practices where Froyd (2008) found strong evidence of both student learning and ease of implementation. The efficacy of approaches that actively engage students in their learning is found in study after study (see Wood 2009). Having students actively engage in their classroom learning, rather than passively processing lectures, aligns well with what we know about how people learn (NRC 1999; NRC 2007). Using learning outcomes and providing students with feedback through systematic formative assessment were also identified as promising practices, along with problem-based learning and case studies. Undergraduate research has been shown to have a number of positive effects on student participants, including increased retention of students from underrepresented groups in STEM fields. Such strategies have been at the core of over two decades of PKAL "What Works" faculty development efforts.

Collaborative learning also scored high in Froyd's analysis. While the evidence for student group work is compelling, there are important, but nuanced, areas with open questions. For example, an important area of inquiry is unpacki

ng why students may be successful in group problem solving but still struggle with their individual efforts (Anderson et al. 2011). Reform teaching pedagogies have enhanced effectiveness in classrooms structured to support student-centered learning across STEM fields. Pioneered with the studio science approach at Rensselaer Polytechnic Institute and further developed and implemented through Beichner's (2008) Project Scale-up, today's students find themselves in high-tech classrooms, seated at large round tables with network access and monitors that allow them to collaboratively view work at the level of the group or entire class. Relatively large-scale studies confirm that structuring the learning environment in this way significantly decreased failure rates and leveled the playing field for men and women. PKAL's Learning Spaces Collaboratory relies on two decades worth of facilities planning to help institutions think creatively and productively about new STEM spaces that will enhance the student learning experience (http://www.pkallsc.org).

Most education research at the undergraduate level has been within disciplines. While much is transferable to learning in an interdisciplinary STEM context, our understanding of what works in specifically enhancing interdisciplinary learning is in the early days. Measuring integrated learning is challenging and instruments like the AAC&U Integrated and Applied Learning Rubric are available for use toward that end (see http://www.aacu.org/value/integrativelearning.cfm.).

FROM EVIDENCE TO CHANGE—DIFFUSION OF INNOVATIONS

No matter how compelling the evidence, it is insufficient to change practice. Fairweather (2008) noted that if more faculty used any of the engaged pedagogies in their teaching, student success in STEM would increase, yet the movement towards twenty-first-century STEM learning has been limited. Learning and teaching centers, including those with a STEM focus, support change at the institutional level. Centers for the Integration of Research, Teaching, and Learning (CIRTL) support graduate students. Within the disciplines, professional development for new faculty can be found in workshop formats, including the Physics New Faculty Workshop and the National Academies and HHMI Summer Institutes for biologists. The biology workshop follows the long standing PKAL model of bringing institutional teams to workshops, in this case pairing a new and a more senior colleague. Within the geoscience community, Cutting Edge provides a hybrid model of workshops and online, community-developed resources that have energized geoscience educators across the country. Disciplinary societies across the STEM fields provide a range of support for faculty to develop as teachers, including collaborative efforts among societies dating back at least to CELS (Coalition of Educators for the Life Sciences) in the 1990s. Both the National Academies and PKAL are actively working with disciplinary societies to enhance professional development for educators. While much faculty development

work occurs within disciplines, PKAL's rich interdisciplinary STEM history provides a vibrant example of positive outcomes when individuals from a range of STEM disciplines and a range of institutional types learn from each other.

There is no silver bullet for STEM education reform. Faculty development efforts show promise, but lack of serious attention to college and university rewards systems provides an ongoing barrier to STEM educational reform at all institutional types (Fairweather 2008). Research on STEM undergraduate education is growing to include a focus on change strategies. Henderson and colleagues (2010) have been leading the way, integrating findings from faculty development and higher education researchers into their work. They classify change strategies into four categories: disseminating curriculum and pedagogy, developing reflective teachers, developing policy, and developing shared vision. Broad scale, meaningful STEM education reform requires not only a solid evidence base, but also a collective will to change and the combined efforts of all stakeholders, including faculty, administrators, and disciplinary societies. ▪

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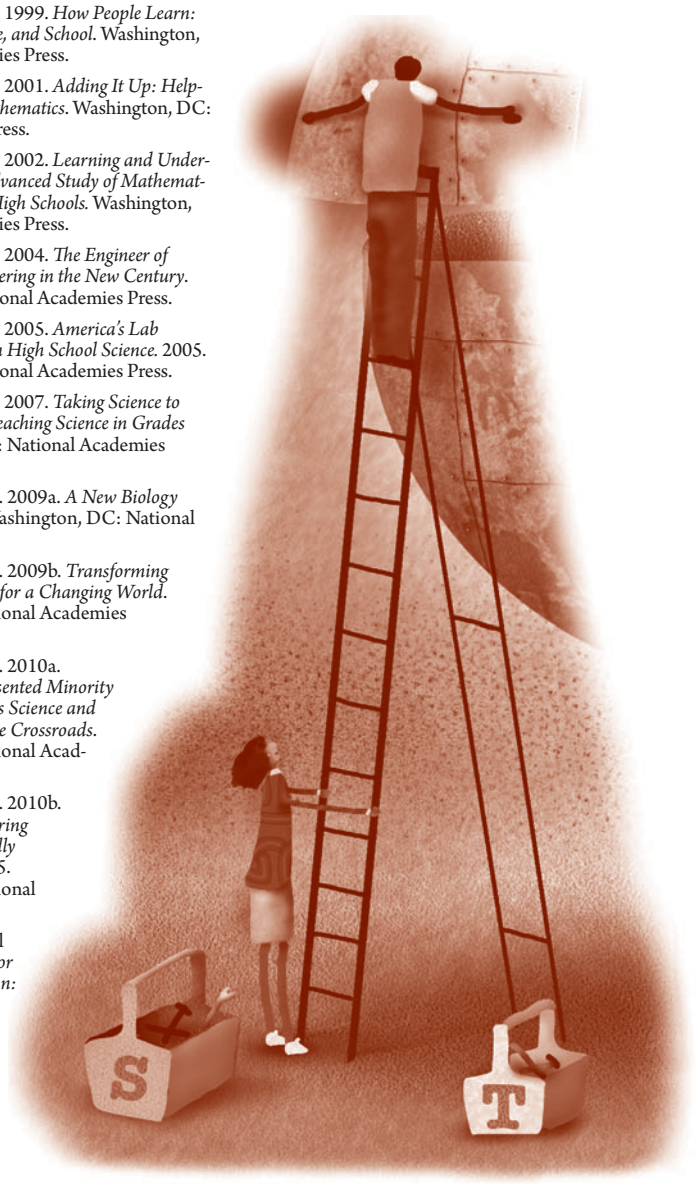

Transforming Science Education Through Peer-Led Team Learning

▸ **Thom D. Chesney,** president, Brookhaven College

In the fall of 2008, a remarkable transformation in undergraduate education was initiated at the University of Texas at Dallas (UT Dallas)—an emerging research university that had only been admitting freshmen since 1991, following a progression from its roots as a research institute to a graduate institution within the University of Texas System to the addition of upper-division students only. Initially crafted as a response to an accreditation requirement of the Commission on Colleges of the Southern Association of Colleges and Schools, the Gateways to Excellence in Math and Science initiative (GEMS) was formally launched at UT Dallas as a comprehensive quality enhancement plan (QEP) with ambitious goals for improving the quality of student learning in science, technology, engineering, and mathematics (STEM) by providing students with innovative, intensive, and active learning experiences both inside and outside the classroom. At its core the project—now in its fourth year—targets success, retention, and persistence in gateway science and mathematics courses that play a critical role in influencing student decisions not only to continue their studies in related degree programs but also to continue their college careers. Originally designed for a five-year rollout, in its first three years GEMS has included a series of interventions, including curriculum alignment and realignment, course redesign, new course design, the introduction of new modes of curriculum delivery, and faculty development. Its overall objectives are to provide a foundation and center for sustainable faculty and administrative activities that increase the retention of students in STEM fields, decrease the number of D and F grades and withdrawals in STEM classes, and create supportive, engaging learning opportunities.

PEER-LED TEAM TEACHING PROGRAM

Of all the innovations and interventions employed to date, none has created more impact and interest and laid the foundation for an academic culture shift than the Peer-Led Team Learning (PLTL) program, which was first offered at UT Dallas in the fall 2008 semester and limited to students taking General Chemistry I—a gateway course required for more than a dozen STEM major degrees and recognized as a potential obstacle for students. In fact, the five years prior to the initiation of PLTL, the course had an alarmingly high 37 percent average for students receiving a grade of D or F or withdrawing altogether from the course—often called the DFW rate. Because of the emphasis that UT Dallas places on STEM and the management of new technologies, introductory STEM courses like General Chemistry I take on an even greater significance and stake for the university's student population. Success in these foundation courses strongly influences student retention within degree programs and their future career options and choices.

The roots of PLTL stretch back to at least the 1980s, and today it is most commonly offered in lower-division STEM gateway subjects such as chemistry, physics, mathematics, and biology. Many post-secondary institutions have recognized that whether students enter as first-time college students or as transfer students with significant progress toward a degree, too many are either ill prepared for these courses, have had too much time lapse between their most recent similar course, or both. Worse yet, these are frequently the courses with the largest section sizes, sometimes numbering into hundreds of students who are often learning in a passive, large-lecture environment in which the closest students will come to a more interpersonal learning experience may be via a required or optional recitation section or exam review session. To combat this, PLTL provides an enticing opportunity for students not only to engage more actively in the learning process but also to become stakeholders in the delivery of course content.

In the UT Dallas application of the PLTL model, students enrolled in PLTL-supported courses have the option to register for a weekly zero-credit, ninety-minute small-group session of eight to

ten students, which is facilitated by another student who has already successfully passed the course. These peers—called PLTL leaders—have recently achieved a course grade of B+ or better and participated in and successfully completed a rigorous interview, orientation, and training program prior to being allowed to lead up to two PLTL sections. In addition to meeting with their students, leaders are closely linked to each other and the instructors of record for the courses they support through the PLTL course liaison program. Faculty liaisons provide the critically important content bridge between the course lecture sessions and the PLTL sessions. Liaisons are charged with creating problem sets, questions for additional thought, previews of future content, and other exercises, depending on the dynamics of the course and feedback gathered from PLTL leaders. Faculty liaisons are recruited and selected as representatives of all faculty teaching a particular course so that the content created for PLTL remains consistent and not all faculty have to invest the extra time commitment to meet weekly with PLTL leaders, respond to e-mails and electronic bulletin board postings, and create twelve weeks or more of PLTL session content. Indeed, a liaison's first year in the program can be the most challenging—everything is new and content must be built from scratch and follow PLTL protocol; they are not paid for their service. Thereafter, however, many faculty liaisons speak to how much they enjoy building their PLTL briefcase by revising prior terms' content, creating new elements, and including their assigned PLTL leaders in the process of continual refinement and renewal.

As for the PLTL leaders' relationship with the students in their weekly sessions, it is largely a facilitative one in which leaders frequently find themselves moving from discussion leader to mediator, depending on the situation. A significant amount of negotiation occurs during any given PLTL session; that is, leaders are often tempted to provide all the steps or options toward solving a problem when the actual answer may be less important than students individually or as a group determining which path to take or how to decode or sometimes infer an alternative approach. This process continually evolves as the PLTL leader clarifies goals of the session, ensures that students engage in the materials and with each other, and promotes interaction and even argumentation.

REDUCING THE DISTANCE BETWEEN LEADER AND LEARNER

As for the UT Dallas PLTL pilot for General Chemistry I, it is important to consider that in a typical fall semester the course is taught in three sections of up to three hundred students each, which can create the appearance of both a literal and perceptual distance between students and instructor and has the potential to make the former feel detached from the latter. However, students who opt in to the PLTL program are in a position to immediately and effectively reduce the distance between leader and learner. After all, to whom is a student more apt to ask a question: a chemistry professor who will be grading exams, or another student who has already successfully navigated the course from start to finish and has a conduit back to the professor via the liaison relationship? Understanding that the learning environment can impact the learning process, UT Dallas renovated a pair of underutilized staff training classrooms into four small, seminar-style classrooms which can support more than forty PLTL sessions each per week.

Initially, only a dozen or so leaders were required to launch the General Chemistry I pilot; for the most part, these were hand-picked by the first faculty liaison and referred to the director of learning resources based upon a record of academic excellence and good interpersonal skill sets. In the interim, the program's growth more than doubled in chemistry and up to twelve different courses in any given fall or spring semester are now supported by PLTL. Today PLTL leaders are hired in a process that parallels a more traditional one: application submission, which includes the recommendation of at least one faculty member in the field for which the student desires to be a PLTL leader; an interview with GEMS Center staff; and—upon offer and acceptance—attendance and active participation at a mandatory orientation and training session that is supplemented throughout the semester with occasional workshops, readings, and mini-assignments (e.g. an end of term reflection paper). Students' enrollment into PLTL and the overall experience thereof have also changed markedly from PLTL's inception to the present format. Initially, the opportunity to participate in PLTL was presented to students in each of the three sections of General Chemistry I during the first week of class. In each case the faculty liaison, who also teaches one lecture section, introduced PLTL, provided background about why it was being piloted, the potential benefits, and the reasons why students should consider voluntary participation. In fall 2008, over 250 students filled out a form to show interest in a PLTL seat, note their preferred time slot, and provide basic contact information. After collecting forms from all course sections, the liaison then spent several hours over three days manually matching student availability to PLTL leader availability, which eventually led to about 160 students being slotted for PLTL.

Today, the process is much more streamlined. Months in advance of the next semester, the GEMS Center receives draft schedules of future chemistry, mathematics, physics and other STEM course offerings, which allows GEMS staff to create a PLTL schedule that will not conflict. The registrar provides access to the enrollment management system for GEMS staff to build what now amounts to about 125 zero-credit sections of PLTL each semester with the capacity to serve over one thousand students who are co-enrolled in the appropriate STEM course. Because participation in the

program is completely voluntary and the benefits are greatest for those who attend sessions regularly, students are discouraged from enrolling to "test the waters" or if they expect to have work, activity, or social schedules that may cause them to miss more than one or two sessions at most.

IMPROVING THE DFW RATE

The integration of PLTL into the UT Dallas STEM learning framework has both fostered and required individuals and teams from across the university to work together year-round. The benefits for students have been notable—occasionally shocking—over the first three years. Consider the pilot group of students who enrolled in General Chemistry I PLTL, for whom the DFW rate was less than 19 percent—an 18 percentage point drop from the preceding five-year historical average. In year two, student enrollment in General Chemistry I PLTL increased by 41 percent to 227 students and the DFW rate for that cohort was an astonishing 9 percent, which effectively put PLTL on the radar of virtually every STEM-oriented program at UT Dallas.

While by no means perceived or declared as a panacea for improving student performance, the PLTL program's ability to replicate gains of the first year led to a series of presentations to internal and external groups including the University of Texas System Board of Regents and several site visits by other institutions who had become familiar with the program through GEMS staff presentations at new student orientations, faculty development seminars, and professional conferences. The third year results for General Chemistry I were more representative of the first—a DFW rate of 16 percent for PLTL students. By this time a total of twelve courses were PLTL-supported including general and organic chemistry, physics (2), mathematics (4), engineering (2), and mechanics (2). Results for these programs in their first year have generally been positive—albeit not as dramatic at those noted for general chemistry—and it must be emphasized that the GEMS program has never argued a purely causal relationship between PLTL and the analysis of the data to date. Simultaneous to the PLTL program, QEP data continue to be collected, for example, on student engagement in STEM degree programs and courses that are undergoing significant redesign, content mapping, and/or curricular realignment.

As PLTL and the ongoing expansion overall of GEMS—now known as Gateways to Engagement, Mastery and Success—services have gradually become an expectation of current and prospective students (and many parents)—the *new normal* for academic support at UT Dallas—the greatest source of new PLTL leaders and peer tutors is the group of students who previously enrolled as a student in a PLTL-supported course. When asked what they like and benefit from most in PLTL sessions, students often say that they expected "pure tutoring" but soon realized that is not at all what PLTL is about and how valuable it was in the long run to have a leader who was a guide to understanding and self-sufficiency rather than a giver of answers.

In summary, from its inception, PLTL at UT Dallas has emphasized students' acquisition and understanding of a variety of techniques, PLTL leaders helping their students when they are stuck or or off course, and leaders providing guidance and encouragement, a structure for group learning strategies, and applied learning. ▪

NOTE

At the time of writing, the author was the associate provost for student success and assessment, University of Texas at Dallas.

Creating Interdisciplinary Science Programs:
Purposes, Progress, Potholes

▸ **Whitney M. Schlegel,** associate professor of biology and founding director of Human Biology Program, Indiana University Bloomington

The founding faculty of the Human Biology Program on Indiana University's flagship Bloomington campus described one of their most important roles in this interdisciplinary science program as "infecting others." Akin to the epidemic metaphor employed by Malcom Gladwell (2000) in *The Tipping Point,* the phrase describes how faculty and students viewed themselves as contagious vectors of positive change and inspired a multidisciplinary community to engage in the difficult intellectual work of building and sustaining a unique interdisciplinary undergraduate degree program in the life sciences.

In 2003–04 Indiana University positioned itself to facilitate and offer leadership in research and education for the state's Life Sciences Initiative. At the same time, the provost created a competitive funding program, Commitment to Excellence, to provide funds for new programs that integrated the research and teaching missions of the university. A proposal for a comprehensive program in human biology was funded under this initiative, supplying the stimulus for the development of an interdisciplinary undergraduate degree program in human biology that would serve the state by attracting, educating, and retaining a life sciences workforce.

A campus conversation was launched with the support of university administration, bringing faculty and students together to explore the meaning of an interdisciplinary program in human biology for the Indiana University Bloomington [IUB] campus. A shared vision began to emerge, leading to a push to mobilize an interdisciplinary learning community.

BUILDING AND SUSTAINING AN INTERDISCIPLINARY PROGRAM

Purposes

The first step in creating interdisciplinary programs is to mobilize a campus community through intentionally structured conversations that challenge faculty and student thinking about educational paradigms that facilitate connections across disciplines. To mobilize the IUB campus, internal and external teaching and learning scholars and interdisciplinary experts were invited to speak with faculty and students and help inform decisions concerning curricular structure, pedagogy, and content for the interdisciplinary undergraduate degree program in human biology.

It was determined that to be truly interdisciplinary, the curriculum must have a place for integration, a core-course series that spans the four-year degree, and it must respect what we know about college student development. To maximize the vast disciplinary expertise of the faculty, the degree program should draw from existing courses and group them in ways that offer unique multidisciplinary perspectives. Foundation courses common to all areas of concentration provide essential quantitative and life science skills and content.

Importantly, while the campus conversation had enhanced understanding of interdisciplinarity within a science context and had achieved the aim of fostering enthusiasm for integrating the natural sciences, social sciences, and humanities across the curriculum, it was unable to break down all barriers. Conscientious efforts to reach out to departments, schools, and other units on campus were required and remain central to sustaining this program. Program events—such hosting as a weekly coffee hour and a brown bag informal speaker series, and cosponsoring invited speakers for departmental seminars—have drawn faculty and students into the interdisciplinary community.

Students were eager to help shape the proposed degree program. They formed a student advisory group during the early campus conversations and this group would go on to become the student government within the program, which involved electing officers, ratifying a constitution, and electing a student member to the pro-

gram's advisory committee. The students assumed a leadership role in the program, convening student call-outs, organizing movie nights, and coordinating unique learning opportunities for students and faculty. Students also serve as peer instructors in the program's core courses and mentors and resident experts in area schools through their outreach activities.

Within faculty discipline and student major reside elements of identity and ownership that are nurtured in part by deep traditions and understandings and that extend well beyond the university. Successfully fostering a shared vision of integrated disciplines and *mobilizing* faculty and students requires uncommon intentionality, communication, and community building with support from all levels of university leadership.

Progress

During the second step, the implementation phase, the program intentionally aligned its approach to teaching and learning with the inquiry habits of mind of its faculty, harmonizing its mission with the mission of the institution. At the first Human Biology Summer Institute, faculty examined active and collaborative learning pedagogies and explored a constructivist-developmental approach for supporting transformative learning. This process yielded the decision to employ a team-based and case/problem-based pedagogy with content organized in three modules, referred to as the 'signature pedagogy' of the program's core. To effectively integrate disciplinary perspectives, it was decided that the core courses would each be taught by two faculty from disparate disciplines.

Baxter Magolda's (1999) work on self-authorship served as the principal guidepost for developing learning goals for the interdisciplinary core curriculum, while Perry's (1998) intellectual and ethical development scheme steered the group's work on student learning outcomes. The use of authentic assessment strategies, such as scientific poster sessions and peer review, were implemented into core course curricula, with the intention of engaging students in the environments and processes inherent to science. All work on learning goals and teaching practices was guided by a backward design approach (Wiggins and McTighe 2000) and the question, "What do we want students to know and be able to do as a consequence of their experiences in human biology?" This approach, coupled with an understanding of where to look for scholarly literature on teaching and learning in the future and how

to access campus resources to assist with teaching, has inspired faculty to continue to ask questions about their students' learning and to design classroom assessments with the dual purpose of facilitating and providing understanding of student learning. Faculty presented their curricular development work, "Putting Theory and Research into Practice in the Development of an Interdisciplinary Undergraduate Major in Human Biology," at the second annual International Society for the Scholarship of Teaching and Learning conference in Vancouver, British Columbia (Schlegel, Halloran, McLeod, et al. 2005).

Faculty decided that students' capacities for connecting their learning in the core curriculum with their areas of concentration and their academic learning with their lives outside academia would be best supported by longitudinal student e-portfolios. The program's electronic portfolio became the work of the program's second faculty cohort and summer institute. Seven competencies (scientific reasoning and inquiry, collaborative problem-solving, integrative synthesis, communication, personal and professional identity, ethical reasoning and action, and civic engagement) were delineated using a matrix model with increasing expectations for integration and student development with each year of advancement.

These competencies were informed by the program learning goals, the scholarly work used in the development of the program, course and portfolio pilots, and the work of national leaders in higher education and science education, including but not limited to AAC&U's LEAP and VALUE initiatives, National Research Council, National Science Foundation, and the work of campuses participating in the Keck/PKAL Facilitating Interdisciplinary Learning (FIDL) Project (http://www.aacu.org/pkal/interdisciplinarylearning). Students were described as "disciplinary explorers" and novice thinkers in their first year, moving to multidisciplinary investigators in year two, interdisciplinary critics in year three, and expert thinkers and "extradisciplinary" advocates in year four. The audience for the e-portfolio shifts with each year and a capstone e-portfolio course guides students in a reflective process that leads to a professional portfolio and a reflective retrospective essay that utilizes the degree program competencies as its frame.

Supporting faculty from diverse disciplines in their understanding of theoretical foundations for teaching and learning and engaging them in evidence-based practices resulted in a shift in their thinking about teaching and learning. In addition, engaging faculty in asking questions about their students' learning and seeking evidence to answer these questions parallels what they do naturally as scholars and has an essential place in fostering best practices, especially

when working across disciplinary boundaries. Providing seamless ways for faculty to connect their disciplinary scholarship and habits of mind with their interdisciplinary teaching may help to facilitate shifts in campus teaching culture and reward structure. Faculty teaching scholarship is a part of the culture of the program and is supported by a larger teaching and learning community that is helping to grow evidence-based practices. As the campus struggles with ways of understanding student learning and its relationship to institution-wide curricular changes and innovations at the school, department, and course level, it is increasingly looking to faculty scholarship of teaching to help with its assessment of student learning. Ernest Boyer (1990) wrote, "The degree to which this push for better education is achieved will be determined, in large measure, by the way scholarship is defined and, ultimately, rewarded."

Partnerships and collaborations are a vital part of interdisciplinary endeavors. The campus instructional support center was an essential partner in the development, implementation, and assessment of the program's curriculum. Partnerships with the School of Education were instrumental in programmatic inquiry and assessment and worked simultaneously to bridge the language differences associated with interdisciplinary student learning in different educational settings. Significant work that has resulted from one of these partnerships is described in a recent book chapter (Eastwood, Schlegel, and Cook 2011).

As part of her doctoral dissertation research, Eastwood examined how learning outcomes and key learning experiences differed between human biology majors and biology majors. Although no differences in content knowledge as determined by the Biology Concept Inventory (Klymkowsky and Garvin-Doxas 2008) were found between disciplinary and interdisciplinary life science majors, the study revealed that the blending of social and biological perspectives within the context of authentic problems and issues in an interdisciplinary program enhanced students' reasoning in novel situations and fostered broader consideration of multiple perspectives when seeking solutions to complex problems. When thinking about new problems, human biology majors frequently referenced case studies they had encountered in their core courses. For these students, situating science within issues, problems, and diverse disciplinary contexts provided a larger repertoire from which to reason.

Experimentation is a natural part of the life cycle of any classroom, course, or curriculum and inherent to faculty work and identity, especially at a research university. Sharing with faculty the evidence for student learning within different learning environments and populations of students provided them with an evidence-based approach to understanding their students' learning and guided their thinking about how best to *implement* courses and curricula.

Potholes

The third and final step in creating interdisciplinary programs is institutionalization, which is by far the most difficult step. The interdisciplinary program in human biology experienced gracious intellectual space and resounding administrative support during its development because it intentionally aligned its mission with the strategic directions of the institution and the state. The program faculty recognized that efforts at all three stages of building and sustaining an interdisciplinary program would benefit from knowledge sharing with other institutions. The opportunity to talk about different approaches and hear the experiences of other PKAL teams in the Keck project on Facilitating Interdisciplinary Learning struggled with the same question—"What is the utility of interdisciplinary programs for our campus and what structures best serve this mission?"—was pivotal in advancing institutionalization of the program.

The faculty crafted governing policies and procedures and sought ways to ensure equitable distribution of leadership across all disciplines contributing to the program. Establishing policies to govern faculty teaching in the program's core curriculum remained elusive in part because initially teaching had been generously funded by the competitive campus award. Later, the variance in departmental cultures within the college and changes in administration would hamper the program's efforts to establish memorandums of agreement and institutionalize procedures for teaching in the program. The program's history has been to rely upon the goodwill of faculty and departments, which is clearly not a sustainable model.

Through formal and informal bridges, the program connected with campus units and mission. Internal and external grant funding was sought for program implementation and assessment, and when appropriate faculty research grants made connections to the program. Faculty and student connections with the K–12 community encouraged recruitment and provided expertise for classroom and outreach activities. Faculty service on myriad campus committees and involvement in college and campus governance helped to inform program decisions and strategic use of resources. Space for the program had been ad hoc from the beginning, and the program's permanent location was in constant flux. The program was able to secure unique space in the heart of campus as a direct consequence of the program's commitment to building bridges and connections.

In May 2009, the program graduated its first class, a class composed of 84 percent women and 21 percent underrepresented minorities in science. Enhancing diversity is one of four strategic directions for the campus and the program directly supports this goal by retaining a high minority (14.4 percent) enrollment and enrolling unusually high numbers of women (74 percent),

especially when compared with other science majors in the college. The issue of underrepresentation within STEM fields for women and racial/ethnic minority students has become a national concern for our colleges and universities (Committee on Underrepresented Groups and the Expansion of the Science and Engineering Workforce Pipeline 2010). Studies have found that strengthening academic support and encouraging social activities for students, especially at the departmental level, fosters a sense of belonging and positively influences retention of undergraduate underrepresented students. The culture of the interdisciplinary program in human biology is one that engages community in the support of learning and encourages student leadership, mentorship, and ownership within the program and through these best practices has cultivated a diverse and robust interdisciplinary science learning community.

Gaining understanding and support for the program from campus leaders was challenged by an unusual turnover in campus leadership that paralleled the program's development. Leadership turned over multiple times at all levels—president, provost, and college dean—by the time the program graduated its first class. Later in that same year the program would experience what Klein (2010) calls, "a perfect storm of political, ideological, academic, and economic arguments, even in the face of counterevidence," forcing changes in program structure and leadership. The program persists with its faculty working to sustain the learner-centered, evidence-based, and community-building best practices; however, it is again facing a new administration and on the heels of adopting significant curricular changes mandated by the previous administration.

We must keep in mind that our students are the true change agents; consequently, how we educate them will be as important as what we teach them, for both will guide how they engage with society. Interdisciplinary programs past and present battle the necessity for employing nontraditional structures to institutionalize their mission. The Human Biology Program experience provides some insights for facilitating learner-centered, evidence-based, and community-minded practices for *mobilizing*, *implementing*, and *institutionalizing* an interdisciplinary STEM program.

WHAT'S NEXT

Lastly, this story offers some cautions for sustaining interdisciplinary STEM programs. The interdisciplinary program in human biology has undergone significant change within the past year that can be best understood in the context of what Henry (2005) describes as "disciplinary hegemony." Changes to the program, and in particular its core curriculum, have occurred as a result of cuts to the program budget, reduced resources for faculty, and removal of class size caps. Confidence in the core curriculum was shaken by claims that the interdisciplinary core courses were shallow and traded rigor for confusing learning objectives that appeared to be more skill than content driven and furthermore, they were costly because of the team teaching and small class sizes. The number of core courses was reduced from four to three and faculty-led seminars have been replaced by graduate student-led discussion sections. The constraints of disciplinary structures, cultures and traditions are an inherent challenge to all forms of interdisciplinary work.

Strong leadership is essential for the persistence of interdisciplinary STEM teaching and learning in higher education. Equally important is the distribution of interdisciplinary program leadership and curricular ownership among a critical mass of diverse disciplinary faculty and students so that the intrinsic culture of experimentation, innovation, and responsiveness to change can continue to be encouraged and mentored. ▪

NOTE

*For additional recommendations and strategies on creating interdisciplinary programs, see the PKAL report, W*hat Works in Facilitating Interdisciplinary Learning in Science and Mathematics *at http://www.aacu.org/pkal/publications/documents/KeckExecutiveSummary.pdf.*

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Twenty-First-Century Quantitative Education: Beyond Content

▸ **Shannon W. Dingman,** assistant professor of mathematics, University of Arkansas
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With the explosion of information and instant communication that is now available to the public,a statement attributed to Bell Laboratories mathematician Henry Pollak comes to mind. As computers became more powerful and ubiquitous in the latter part of the twentieth century, Pollak observed, "With technology, some mathematics becomes more important, some mathematics becomes less important, and some mathematics becomes possible." As computers, the Internet, and Dick Tracy-like communication have immersed society in an environment alien to that in which many of us were educated, various analogs to the Pollak statement apply to different aspects of the educational landscape—that is, some things are more important, some less, and some now possible. This is especially true in the general education sector of mathematics and science education, where we work to move college students toward sound and effective quantitative reasoning (QR). How should quantitative education—and really, education as a whole—evolve to reflect the growing capabilities and demands of life in the twenty-first century?

NEW POSSIBILITIES

Any list of specifics made possible by the technological advances and sociological changes of recent years risks being out-of-date and incomplete within a few months. However, new possibilities affect quantitative education and how we can work to enhance student abilities to make sense of and effectively use the wealth of information around them. Some involve visualization, such as graphical representations of large data sets and geometric modeling. Others result from the almost instantaneous availability of information and questions surrounding validity of that information. This environment opens up new avenues for investigating and conjecturing, for allowing the curious to explore and reason, and for more complex real-life problems to be analyzed and understood. Yet they also place new demands on the explorer concerning the challenges of possibly accessing incorrect or misleading information. These factors, therefore, increase the demands for sound QR.

These new possibilities have influenced the creation and implementation of a QR course we teach to hundreds of arts and humanities students each semester at the University of Arkansas. Many of these students are quantitatively phobic and are averse to technology, save that involved in rapid communication (e.g., texting and e-mailing) and retrieval of information (e.g., through Google searches). This QR course has developed over the past seven years in the dizzying environment of changing technology. For curricular materials, we use media articles as the prompts for investigation. In particular, we began a decade ago with newsprint as the course first emerged. Since, we have found that few current students use newspapers and magazines as primary sources of information, but rather turn to the Internet as a guide. Nonetheless, regardless of the delivery medium, public media still chronicle the everyday world of our students, and they find QR in this everyday world at the same time interesting and challenging. Upon entering our course, the most serious weakness we have observed in many students' mathematical competency is what was termed "productive disposition" in the National Research Council Study Report, *Adding It Up* (Kilpatrick, Swafford, and Findell 2001, 31). As described there, "Productive disposition refers to the tendency to see sense in mathematics, to perceive it as both useful and worthwhile, to believe that the steady effects of mathematics pays off, and to see oneself as an effective user of mathematics."

This weakness no doubt results from flaws in our system of mathematics education, and it is now both possible and critically important that this weakness be corrected. Quantitative reasoning in today's US society is no luxury or elective; it is an essential!

There are several aspects of our QR course that we believe adapt strongly to the current educational environment. First and foremost, the course is not organized by mathematical topics or the development of mathematical content, but rather is driven by quantitative societal issues reflected in public media (e.g., fuel efficiency, the national debt, credit card payments). Additionally, the course caters to student interests and current events, and provides a venue for continued practice beyond both the course and formalized schooling. One facet that allows students' interests to emerge is News-of-the-Day, a course component where students bring to class media articles with quantitative content to present and explain. This, of course, leads the class to unplanned and often unfamiliar areas of discussion (including for the instructor). At times we need information, and in some classes a student volunteer becomes the designated "web surfer," using a laptop or smartphone to provide key information such as definitions, populations, or other required data. In this pedagogical model, the instructor feels the shift away from being a dispenser of knowledge into being a moderator—clearly no longer the sage on the stage. This new role is a major change for faculty—from the fount of knowledge to the adjudicator of reasoning—and requires according pedagogical adjustments.

Quantitative reasoning in today's US society is no luxury or elective; it is an essential!

MORE IMPORTANT AND LESS IMPORTANT

Traditional content areas of mathematics—real and complex numbers, algebra, geometry, calculus, and more—dominated our educational experiences, and continue to dominate K–12 and collegiate mathematics. The power of this content has not diminished, but different aspects of it have become more important in QR education. Traditional educational practices have made students wary of and unprepared for dealing with the often fuzzy and ill-defined, yet very real, problems of their contemporary surroundingsOur QR students show very weak understanding of using their knowledge of school mathematics to solve real-life problems that emerge from the media articles. Contributing to this poor understanding is students' inadequate recall of school mathematics, which is due to lack of practice—they have not used it and, therefore, many have lost it. Additionally, the contexts of the media articles are different from the contexts of the application problems in school. These points argue for more relevant and varied contexts for applications in school and for more coordination of education in the various disciplines. QR contexts cover the spectrum of human activity—economics, health, politics, sociology, art, as well as science and engineering. The utility of developing and using interdisciplinary units to enhance student QR skills is obvious—the challenge is carrying this out. Over the past three summers, we have worked with grades 7–12 mathematics and science teachers to help them better understand QR and to develop investigations involving media articles that can be used in their classes. This cooperative effort aims to strengthen student QR abilities prior to college, and more is needed at both the K–12 and collegiate levels.

QR in everyday life is heavy on proportional reasoning, for example, to understand the quantities one encounters. "Just how big is this number?" "How can we know?" School algebra is of little use. Geometry will not help. This is not the mathematics of Euler and Euclid—it is the quantitative environment of the twenty-first century. How can we make sense of the size of the annual US military budget of $700 billion? How does it compare to the military spending of countries around the world? Just how large a quantity is the US national debt of $14 trillion? It is actually somewhat less than the current gross domestic product of the United States. How is this analogous to a person having a debt of one year's income? These questions are very much part of US public discourse at the moment, and many similar questions arise regularly in political and social arenas. These questions are important, yet the ambiguity involved in formulating answers requires flexibility in student thinking.

Whereas traditional mathematics spends considerable time in producing and manipulating representations, too little time is spent making sense of these representations. Yet today, rote procedures are less important because often they can be performed by technology or have no broad application. For example, after seeing the development of the formulas for and the connections between combinations and permutations, our students rely on their calculators for computing these counts. However, knowing the limitations of technology and what to do to push beyond those limits is important. For example, in calculating the probability that no two people among forty have a common birthday, students produce a quotient with a denominator and a numerator that will overflow many hand-held calculators, but rewriting the probability quotient as a product of forty quotients will push beyond this limitation. Summing the results of a daily compounding of interest in an installment savings problem can also exceed calculators' capabilities, giving reasons to develop the closed sum of a geometric

series while recording where it came from. When there is a clear and present reason to use algebra, even our math-phobic students appreciate the effect. Traditional high school and nonmajor mathematics courses generally focus on calculation and manipulation of mathematical representations (functions, equations, expressions). Of course, this is still important, and regardless of the fact that much of this can be done by technology, understanding how it is done remains important. However, QR education (and many other learning outcomes) requires that we broaden teaching to include competencies such as interpretation of information and data, developing and evaluating assumptions, conducting analysis and synthesis of solutions to make sound judgments and conclusions, and communicating one's thoughts in an organized and coherent manner.

THE MESSY WORLD OF REALISM

The complexity and messiness of real-life quantitative situations tax one's perseverance, disciplinary knowledge, and investigative habits. Students (and everyone) need to develop dispositions toward questioning and investigating. Knowing what to do when one does not know what to do is critical. Finding information is a breeze, but knowing if it is trustworthy has become a whole new ballgame in recent years. The professor and the textbook were trusted sources and remain so, but many other sources present themselves in classes such as our QR course. How does one know if information from Internet sources is reliable? One major criterion for trustworthiness we urge our students to utilize concerns the consistency of information with what they know. This opens up a whole new area of need because this criterion depends on what one knows. We refer to this knowledge as personal quantitative benchmarks. Sometimes these are as simple as knowing the approximate population of the US. However, sometimes the benchmark may be more complex—for example, knowing that more frequent compounding of interest on a savings account will increase the balance. In his 2008 book *Stat-Spotting*, Joel Best lists a few quantitative benchmarks needed to understand US social statistics. Three basic ones are the US population, and the annual number of births and deaths in the US. Building up an inventory of personal quantitative benchmarks promotes further investigation and evaluation of information, leading to the habit of mind that is quantitative literacy. Habits are developed by continued practice, making provision of venues for practice beyond the classroom and school critically important in various areas of reasoning and rationalization.

Connected to the issue of quantitative benchmarks and validity of information is the issue of quick and efficient evaluation of information to decide if further investigation or vetting is necessary. While reading quantitative arguments or assertions in public media, one needs to be able to detect when arguments or assertions seem correct or flawed. Detection can depend again on what one knows, but it can also result from approximate calculations involving the quantities in the argument or assertions. Grabbing a calculator or a pencil is often inconvenient or impossible. Thus one relies on mental calculations, estimation, and ad hoc reasoning. One of the bad results of calculators in schools is an overreliance for even the simplest calculations, producing students unpracticed at mental arithmetic. Some students seem inclined toward on-the-fly thinking, and some profess that it is because they believe they are avoiding work. In fact, mental calculation can lead to sound examples of QR. For example, one of our students illustrated on-the-fly thinking in answering a question regarding the amount of the 2001 US federal budget. This question stemmed from a statement by economist and columnist Paul Krugman that $1 billion per month (the estimated cost of the war on terrorism) was about one-half of one percent of the annual federal budget (in 2001). "Well," said the student, "one half of one percent is $12 billion, so one percent is $24 billion, and 100 percent is $2,400 billion, or $2.4 trillion."

THE COMPLEX LEARNING OUTCOMES LANDSCAPE

Moving away from channeled disciplinary education to cross-disciplinary education with increased attention to reasoning and other cognitive processes has prompted considerable thought to a structure for learning outcomes. One example provides some hint of the complexity of possible landscapes. The intricacy of these learning outcomes structures reflects the challenges of mathematics and science education, of all education in the twenty-first century. AAC&U's Valid Assessment of Learning in Undergraduate Education (VALUE) project provides rubrics to evaluate achievement of learning outcomes, including intellectual and practical skills and areas of personal and social responsibility and integrative and applied learning. These include inquiry and analysis, critical thinking, written communications, and quantitative literacy, among others. The quantitative literacy VALUE rubric contains six core competency areas—interpretation, representation, calculation, application/analysis, assumptions, and communication—and four performance levels for each competency area.

The rubrics are intended for institutional-level use in evaluating and discussing student learning. We used the quantitative literacy VALUE rubric, however, as a springboard for thinking about assessing students' QR. Because messy and complex QR problems lead to complicated assessment of student learning, accurately scoring student responses is both more difficult and more important than ever before. Multiple-choice tests are rarely an option here. Assessing QR calls for attention to reasoning structure and scoring rubrics that are more complex than those used to score simple calculations, which comprised much of what we scored in the past. Along with colleagues Stuart Boersma and Caren Diefenderfer, we modified the VALUE rubric to one that we successfully used to score individual student work in answering study questions from our QR casebook used in our QR course. The major value of the rubric, as we discovered, was not just in the consistent scoring it provided, but also in the assistance it provided for preparing course materials and assessment tasks and for helping to guide student thought processes in QR.

CONCLUSION

Being an informed and productive citizen in the twenty-first century is more complicated than ever before, and the educational experiences we offer to students need to reflect this complicated world in which they operate. Traditional education has long centered on content to drive learning, with the surrounding skills and processes being developed from student work with the content. However, with continuing evidence that students are not gaining the skills they need and with technology providing greater access to working with content, we must consider how traditional education can better support the development of these skills and produce students better equipped for citizenship and the workplace. This is not to suggest that content should be ignored; in fact, we must work to ensure that students possess both the knowledge *and* skills desired of a learned citizenry.

Our work in QR education is in a small corner of this broad educational picture, but we believe our experiences are meaningful across much of the landscape. Indeed, one component of the educational system that has become more important is synergistic teaching and learning. The same processes we promote in QR should be the processes in physics, chemistry, economics, and biology. The QR core competencies—as we use them—of interpretation, representation, calculation, analysis and synthesis, assumptions, and communication have closely related competencies in all subjects. These core competencies can be used to examine whether the learning experiences provided to students truly capture the nature and breadth of skills needed to be successful in the twenty-first century. Our world is ever changing, and it is therefore vital that the education provided to students evolves as well in order to develop citizens that are well prepared for the world they encounter. Much of our work is reported in *Numeracy*, the journal of the interdisciplinary National Numeracy Network (NNN), where other resources for assessing QR can be found. ▪

ACKNOWLEDGMENTS

Development of the quantitative reasoning course discussed in this article has been supported by a National Science Foundation grant (DUE-0715039) and by two colleagues, Caren Diefenderfer at Hollins University and Stuart Boersma at Central Washington University. Similar courses are being taught at Hollins University and Central Washington University.

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Interdisciplinary Problem-Solving to Advance STEM Success for All Students

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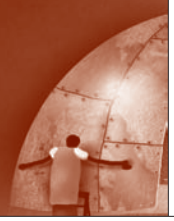
In 1980, Congress took decisive action on the national paucity of opportunity, access, and success of underrepresented minorities in science, technology, engineering, and mathematics (STEM) by mandating that the National Science Foundation (through the Science and Engineering Equal Opportunities Act) develop the STEM talents of the country's citizenry irrespective of gender, ethnicity, race, and economic background. Now, some thirty years later, this battle still rages on with no clear, comprehensive victory in sight. Many—if not most—of our twenty-first-century challenges will coalesce around STEM, dealing with issues ranging from such medical dilemmas as drug-resistant bacteria, to the scarcity of natural resources, to oil spills and climate change. Solutions to these challenges will require a workforce armed with a skill set that engenders technological sophistication and interdisciplinary thinking. It is, therefore, critical to train and engage a diverse workforce so as to provide foundational STEM education for the nation's citizenry with all of its inherent diversity. Both mathematics and science education must be radically improved. According to a recent National Mathematics Advisory Panel (2008) report, "American students have not been succeeding in the mathematical part of their education at anything like a level expected of an international leader."

It is, therefore, critical to train and engage a diverse workforce so as to provide foundational STEM education for the nation's citizenry with all of its inherent diversity.

To better prepare our diverse student body for these future challenges, New York City College of Technology (City Tech) has made engagement for *all* students in STEM disciplines an institutional goal. City Tech is the senior college of technology among the twenty-three campuses of the City University of New York (CUNY), the largest urban public university system in the nation. The college awards both associate and baccalaureate degrees in liberal arts and career and technical fields. In fall 2010, with a student population of 15,368, 31.7 percent of students self-classified as Hispanic, 34 percent as African American (non-Hispanic), 18.5 percent as Asian/Pacific Islander, 11 percent as white, 0.5 percent as Native American, and 4.3 percent as other. Additionally, 67 percent are the first in their families to attend college and 52 percent reported a household income of less than $30,000. Seventy-eight percent of incoming first-year students received need-based financial aid and 30 percent of students reported working twenty or more hours per week.

To better serve those populations, our institution embraced interdisciplinary learning because of its many benefits to student



learning, in general, and to the integration of STEM knowledge, in particular. Interdisciplinary studies nurture and enhance the ability to assemble (locate, organize, and evaluate) ideas and information from disparate sources into a coherent whole; the ability to function within a team setting; the ability to apply knowledge and skills to real-world problems; and the ability to effectively communicate complex cross-disciplinary problems both orally and in writing. Interdisciplinary studies involve two or more academic subjects or fields of study that synthesize broad perspectives, knowledge, skills, and epistemology in an educational setting. It focuses on questions, problems, or topics too complex or broad for a single discipline or field to cover adequately, and they specialize in highlighting connections between seemingly exclusive disciplinary domains. In order to advance our interdisciplinary initiative, we participated in the Keck/PKAL (Project Kaleidoscope) Facilitating Interdisciplinary Learning (FIDL) Project (http://www.pkal.org/activities/PVIIDST.cfm). This initiative has benefited City Tech by providing the support required to improve the university's commitment to interdisciplinary STEM pedagogy and the concomitant success outcomes for underrepresented populations.

City Tech's initiative focused on two areas: engaging student interest in interdisciplinary learning and establishing a faculty interdisciplinary STEM community. To this end, we created an interdisciplinary course that provides students with the opportunity to explore various interdisciplinary topics, such as what it means to be human. Students who take the course experience a continuum of research experiences—from library, to laboratory, to the actual physical environment of the college. A focus on both real-world problems and hands-on experimentation has proven motivating to all students, but especially those whose prior preparation in STEM may have been limited. We have also created a faculty learning community, which brings together the many strands of reform and innovation currently underway at City Tech in order to devise a coherent interdisciplinary STEM curriculum that features learning goals, implementation strategies, and measurable learning outcomes. This community exemplifies the collaborative approaches that characterize the organization of current technological work and represent the future of science. By demonstrating the effectiveness of interdisciplinary learning in STEM, City Tech will be able to provide significant guidance to peer institutions also challenged by a diverse, underprepared student body.

STUDENT-CENTERED COMPONENT OF INTERDISCIPLINARY LEARNING

In order to create an interdisciplinary community of problem solvers and inspire a nation of STEM learners, City Tech created an interdisciplinary STEM prototype of programs that is state-of-the-art and transformative. The student component of the prototype for STEM education is rooted in the following three main areas: (1) the Black Male Initiative (BMI), a STEM-designated program; (2) Peer-Assisted Learning; and (3) an interdisciplinary course, Weird Science: Interpreting and Redefining Humanity.

The BMI and Its Interdisciplinary Strands

City Tech has created a new coordinated initiative to attract, retain, and graduate African American male students in the STEM disciplines. STEM was selected as the area of focus not only because of the national STEM crisis among minorities, but also because the STEM disciplines are among the college's flagship and strongest programs and these areas of study are those in which African Americans are notably underrepresented. Increasing the numbers of underrepresented minority students who succeed in STEM disciplines is important not only to the economic vitality of the New York metropolitan area, but also to the nation as a whole. As such, the BMI serves as a prototype for future cohort-based initiatives that address the needs of other educationally underserved populations in higher education that have not been advantaged equally. A key component of the project will be to maximize the exposure of all students to successful African American scientists and engineers, to nurture relationships between our students and practicing scientists and engineers, and to adapt to the needs of our institutional approaches to STEM education that have proven to be so successful at Historically Black Colleges and Universities.

Since its inception six years ago with fourteen students, the BMI program has grown to over four hundred students today, and BMI students have higher STEM retention rates, graduation rates, and mathematics persistence rates than non-BMI STEM students at City Tech. This better performance by the BMI students (we believe) is at least in part due to a major cornerstone of the BMI program—its focus on providing interdisciplinary learning experiences for its students. Not only does the program provide interdisciplinary learning experiences via the interdisciplinary Peer-Assisted Learning modules described below, but it also has a well developed, structured interdisciplinary research component whereby some BMI students engage in interdisciplinary research (ex. Satellite and Ground-Based Remote Sensing of the Environment, Climate Change Impacts on Health, Water Resources, Energy, Agriculture, etc.) and present this research (orally and by poster at various national and local conferences). Additionally, the BMI exposes its students to a variety of research areas in disciplines different from their own by taking them to the Brookhaven National Laboratory

where they are exposed to interdisciplinary project synthesis and where their awareness of interdisciplinary learning is heightened and challenged. The many STEM exposure trips that the students take to museums along the East Coast make up the third strand of the BMI interdisciplinary approach. Some trips have several STEM projects attached to them, and the students (from different disciplines) work collaboratively in teams to complete the projects. We, therefore, believe that interdisciplinary team learning can play a pivotal role in increasing the achievement of students who are traditionally underrepresented in STEM.

Peer-Assisted Learning

Supportive learning environments are essential in helping undergraduates, especially underrepresented minorities, in the sciences and mathematics. Peer-Assisted Learning (PAL)—a vital component and corner-stone of the Black Male Initiative Program and a bedrock program at City Tech—is a form of instruction adapted from the Peer-Led Team Learning (PLTL) student-centered instructional model wherein students actively learn in a small group, facilitated by a peer leader. Since mathematics is the gatekeeper of many science and engineering disciplines, PAL mathematics workshops are designed to provide an academic support system with a peer leader to assist as a role model and facilitator. The goal of the PAL mathematics workshops is to build a community which maintains a safe setting for students to question and challenge concepts, to integrate various problem-solving strategies, and to communicate ideas while working collaboratively on mathematical modules with interdisciplinary themes. A typical PAL mathematics workshop consists of eight to ten students who meet regularly with a peer leader for one hour a week for twelve weeks. The team works collaboratively on modules that are conducive to meaningful group discussions while encouraging diverse learners to reinforce their understanding of the course materials.

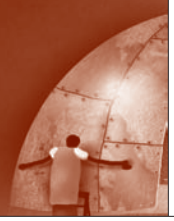
The workshop provides an opportunity for students to discuss their understanding of the concepts in a nonthreatening environment. The peer leader guides by asking questions, providing hints and immediate feedback, and encouraging a positive learning atmosphere. The modules used in the PAL mathematical workshop are designed to increase critical thinking skills, enhance problem-solving abilities, and strengthen computational proficiency. With the goal of increasing the students' ability to transfer the language of mathematics to the sciences, modules with interdisciplinary themes are used to highlight key concepts. Real-world examples provide students with a sense of significance and applicability. Students also review specialized mathematics vocabulary and learn how to identify the relevant mathematics operations needed to solve problems. This pedagogical paradigm of student engagement is found to be effective in promoting success in mathematics.

City Tech has also created a community of peer leaders to address the retention efforts of underrepresented students in STEM courses. These peer leaders facilitate workshops for courses that they have taken successfully (B+ or higher). They are recruited based on their STEM majors, GPA, and interpersonal and communication skills. The peer leaders play an indispensable role in providing guidance for the group by ensuring that the team actively engages itself with the appropriate mathematical concepts and with each other, thereby building commitment and confidence among the students and constructing meaningful deliberations and discussions. Because they have previously taken the course, the peer leaders understand the challenges, nuances, and misconceptions of the course material. They, however, do not give away answers, but rather offer well-timed assistance when the group members find themselves in difficult situations as they solve the problems collaboratively. The peer leaders are trained through a one-credit course. The course goals for the students are to implement pedagogical techniques in workshops, write about their workshop experience and their roles as peer leaders using learning theories, and understand the emphasis and the impact on students' learning in a collaborative setting. A weekly reflective journal revealing the development of workshop practices is required. These peer leaders are also provided a first-hand experience in conducting a mini-research project by examining their practice with a learning theory based on their experience.

Approximately 500 students have participated in the PAL workshops from academic years 2008–2011. Workshop participants have shown to have a range of approximately 11–24 percent higher grades than the college's overall grade distribution. Moreover, the community of peer leaders has been supportive in retaining and graduating STEM students. From a total of fifty-five peer leaders, 12.7 percent are in either graduate, medical, or pharmacy school; 16.4 percent have graduated with a STEM degree and are applying to graduate school; and 52.7 percent are still retained in their STEM disciplines.

Weird Science: Interpreting and Redefining Humanity

Another strand of our interdisciplinary prototype is the development, implementation, and offering of a new course we call Weird Science. This writing-intensive course, which incorporates digital media, allows students to explore the literature of shifting and expanding definitions of *humanity* and *post-humanity*. The course goals are to provide and engage students with an understanding of ideas and connections in the natural and social sciences, technology, and engineering.



This includes: (a) cultural factors that affect these disciplines; (b) philosophical, historical, and ethical perspectives; (c) methods for finding pertinent information; (d) critical evaluation of ideas and their sources; (e) developing the critical writing skills to discuss these ideas in an academic context; and (f) using multimedia and simulations to communicate information.

This course focuses, first, on being human and then on being human virtually. Initial topics covered medical interventions in the body (e.g., the effect of having an artificial limb, heart, or face transplant on a human being) while later topics, on being virtually human, included artificial intelligence (from Turing to Watson) and simulations. In spring 2011, this course was offered to ten students. There were guest lecturers from different disciplines—African American studies, philosophy, education, biological sciences, psychology, sociology, computer systems technology, entertainment technology, and physics—who offered their perspectives and, as students gradually realized, their biases too. Student assignments involved the integration of insights from disparate disciplines through collaboration, creativity, and critical thinking. This communication core course is geared towards second-semester students who may otherwise not be exposed to, for example, physics or sociology in their entire college career. This course is also being considered as a capstone course for seniors. In this way, upper-level students can provide peer support to lower-level students.

FACULTY-CENTERED COMPONENT OF INTERDISCIPLINARY LEARNING

The objective of the faculty component of City Tech's interdisciplinary learning prototype is to develop and sustain an interdisciplinary faculty learning community that creates and implements strategies for interdisciplinary teaching and scholarship. Campus-wide interdisciplinary workshops and seminars were conducted. For example, to further encourage and advance an interdisciplinary faculty learning community for teaching and scholarship, a three-part workshop series on creating, implementing, and assessing interdisciplinary STEM projects was conducted by nationally renowned leaders in interdisciplinary learning. These experts not only led the workshops, but also incorporated guided work sessions within the workshops so that the City Tech faculty were given hands-on experience in these three critical areas of interdisciplinary learning. A main focus of the workshops was to assist faculty in developing interdisciplinary projects for both extant and new courses and to formulate effective evaluation processes.

Twenty-five City Tech faculty members participated in these workshops, and from these workshops many cohesive interdisciplinary curricula (like the Weird Science course above) were created and implemented. Additionally, an Interdisciplinary Curriculum Committee for the institution's School of Arts and Sciences was chartered to provide leadership and comprehensive support for interdisciplinary initiatives, and a survey to gain baseline data on existing campus interdisciplinary activities was implemented and analyzed. The results of the analysis have provided guidance about how to strategically continue to establish interdisciplinary learning at City Tech.

PROJECT FINDINGS

As a result of the intentional interdisciplinary learning experiences we have created, students at City Tech were able to

- recognize disciplinary strengths, processes, limitations, and perspectives;
- purposefully connect and integrate knowledge from across the disciplines to solve problems;
- synthesize and transfer knowledge across disciplinary boundaries, in the context of novel situations;
- be agile, flexible, reflective thinkers who are comfortable with complexity and uncertainty, and can apply their knowledge to respond appropriately and positively;
- understand that other factors—cultural, political, ethical, historical, and economic—must be considered when addressing the complex problems of this century;
- understand the universal nature and deep structure of science, as well as its relationship to other disciplines;
- prepare for future learning as lifelong learners in their careers and as citizens;
- apply their capacity as integrative thinkers to solve problems in ethically and socially responsible ways;
- think critically, communicate effectively, and work collaboratively with others within diverse cultures and communities.

As we begin the second decade of this young century and this young millennium, this nation (if it is to maintain its global competitive edge) needs to seriously contemplate, fund, and implement science initiatives with interdisciplinary underpinnings. In light of energy crises, natural disasters, new diseases, and a plethora of other major concerns that threaten our very survival, a failure to act now could well imperil humanity. This defining period may well be our nation's second Sputnik moment. May its challenge, therefore, be met with the same vigor, discipline, intentionality, and optimism. ▪

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STEM/Non-STEM Differences in Engagement at US Institutions

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A recent paper by one of us (Nelson Laird) and some colleagues brought some sobering news of differences between STEM (science, technology, engineering, and mathematics) and non-STEM undergraduates with regard to approaches to learning that promote more complex, deeper understanding. Using data from the National Survey of Student Engagement (NSSE) and the Faculty Survey of Student Engagement (FSSE), Nelson Laird and colleagues examined disciplinary differences in the extent to which students are exposed to educational environments that promote deep approaches to learning. These approaches to learning are important because "[s]tudents who use deep approaches to learning tend to perform better as well as retain, integrate, and transfer information at higher rates than students using surface approaches to student learning" (Nelson Laird, Shoup, Kuh, and Schwarz 2008, 470).

Nelson Laird and colleagues found—using models with extensive statistical controls—that, nationally, STEM faculty generally use pedagogies that encourage higher-order, integrative, and reflective learning significantly less than faculty in non-STEM fields and, not coincidently, STEM seniors experience "deep approaches to learning" less than seniors in non-STEM fields (for descriptions of the three measures, see Nelson Laird et al. 2008). The differences were small for Higher-Order Learning, the scale that is concerned with analysis, synthesis, and judgment regarding evidence—relatively good news—but quite large for the Integrative and Reflective Learning scales.

The study by Nelson Laird and colleagues is a part of a larger body of work about students engaging in educationally purposeful activities—those educational practices known to positively influence valued educational outcomes, activities such as active and collaborative learning and those that involve much student–faculty interaction, as noted in many of the articles in this issue of *Peer Review*. We know of the positive impact of pedagogies of engagement not only on general student learning, but also on STEM learning, from years of research.

It is discouraging that, nationally, faculty in STEM fields tend to have lower expectations for integrative and reflective learning relative to other faculty, and that results from seniors reflect those differences. The Integrative Learning scale assesses how often students use ideas from various sources and courses, include diverse perspectives in class discussions or writing assignments, and discuss ideas from readings or classes with faculty members and others outside of class. The Reflective Learning scale is a combination of responses to questions about trying out different perspectives and thinking about one's own beliefs. The kinds of intellectual self-reflection skills these questions are about are surely as important in the STEM disciplines as they are in other disciplines, but we see that STEM majors have far fewer opportunities to develop these skills than students in other majors. Indeed, one might argue that it is especially in STEM that students should acquire these skills, given the way empirical evidence tends to be seen as harder in science than in other disciplines. Discovering a bad premise or assumption and being open to other interpretations are just as important in STEM disciplines as elsewhere.

These results caused us to want to look more closely at STEM/non-STEM differences and to determine whether there are circumstances where STEM seniors buck the general trends and are as engaged or more engaged than their non-STEM peers.

LOOKING DEEPER

For our analyses we used responses to the 2008 NSSE survey from 614 institutions. From these institutions we selected seniors in all STEM fields categorized by NSSE: biological sciences, computer science, engineering, physical sciences, and mathematics (27,428 STEM seniors). Then, to keep the comparison group similar at each institution, we limited non-STEM majors to seniors in the arts and humanities and the social sciences, fields that are represented on the vast majority of college and university campuses (46,178 non-STEM seniors).

We used seniors' responses to the three Deep Approaches to Learning scales and, to capture a broader picture of their engagement overall, their scores on NSSE's Active and Collaborative Learning and Student–Faculty Interaction measures. Active and Collaborative Learning covers how often students ask questions in class, work with classmates in and outside of class, tutor or teach others, participate in community service, and discuss ideas from class with students, family members, coworkers, and others outside of class. Student–Faculty Interaction captures how often they discuss grades or assignments, discuss ideas from readings or classes outside of class, talk about career plans, and work on activities other than coursework with their faculty. It also includes how often students receive prompt feedback from faculty on their academic performance. In addition to broadening the focus, these extra measures tap aspects of engaged pedagogy much discussed and advocated among STEM reformers (Fairweather 2009).

The first thing to report is that the STEM/non-STEM differences Nelson-Laird et al. reported for the 2005 NSSE data were reaffirmed in the 2008 data—a small negative difference (i.e., the STEM average was below the non-STEM average) on High-Order Learning, but larger negative differences for Integrative and Reflective Learning. The difference was also small and negative for Student-Faculty Interaction, but small and positive (i.e., the STEM average was above the non-STEM average) for Active and Collaborative Learning. All differences were statistically significant.

Beyond the general effects, we were interested in what was happening at the institutional level. To examine this, we ran hierarchical linear models that produced adjusted means and estimated the STEM/non-STEM difference for each engagement measure at each institution. The models adjusted for the number of students at the institution (a data quality issue) and student characteristics (gender, race, first-generation college student status, living on campus, transfer status, foreign citizenship, full-/part-time status, Greek affiliation, and STEM/non-STEM major).

Our next step was to select the one hundred top scoring institutions (those with the highest adjusted means) for each of the five engagement measures and compare the composition of those groups of one hundred institutions to the composition of all 614 institutions (see table 1). What we see in table 1 is that Research Universities are underrepresented on all measures—indeed, no Research Universities make the top one hundred for Higher-Order Learning or Student–Faculty Interaction. Baccalaureate Arts and Sciences institutions, on the other hand, are overrepresented in the top one hundred on all measures. Baccalaureate Diverse institutions are underrepresented among the top one hundred institutions for the three Deep Approaches to Learning measures and overrepresented among the top one hundred for Student–Faculty Interaction. Private institutions are greatly

TABLE 1. DISTRIBUTIONS OF TOP ONE HUNDRED SCORING INSTITUTIONS FOR EACH OF FIVE ENGAGEMENT MEASURES BY INSTITUTIONAL CHARACTERISTICS

		DEEP APPROACHES TO LEARNING			OTHER NSSE MEASURES	
	All Institutions	Higher Order Learning Top 100	Integrative Learning Top 100	Reflective Learning Top 100	Active and Collaborative Learning Top 100	Student-Faculty Interaction Top 100
CARNEGIE CLASSIFICATION						
Research	11%	0%	4%	7%	1%	0%
Doctoral/Research	4%	6%	6%	6%	4%	0%
Master's L	27%	16%	15%	17%	25%	15%
Master's M	13%	10%	9%	14%	15%	16%
Master's S	7%	7%	5%	5%	12%	8%
Bac/A&S	22%	57%	53%	40%	29%	40%
Bac/Diverse	15%	4%	8%	11%	14%	21%
SECTOR						
Public	42%	14%	15%	22%	24%	18%
Private	58%	86%	85%	78%	76%	82%
BARRON'S SELECTIVITY						
Competitive plus or below	64%	33%	43%	46%	70%	70%
Very competitive or above	36%	67%	57%	54%	30%	30%

Note. For descriptions of the Carnegie Classification see classifications.carnegiefoundation.org. For more on Barron's selectivity ratings, see Barron's Profiles of American Colleges 2011.

overrepresented among the top one hundred institutions on all measures. With regard to selectivity, institutions ranked as Very Competitive or above on Barron's selectivity rating are overrepresented on the three Deep Approaches to Learning measures, but they are slightly underrepresented on Active and Collaborative Learning and Student–Faculty Interaction.

Institutions underrepresented in the top one hundred columns generally have higher than average proportions of STEM majors—a drag on their scores. This is particularly true for Research Universities where there is near parity between the proportions of STEM and non-STEM majors as we have defined them. An additional drag on Research Universities' scores is their relatively high proportion of engineering majors among the STEM majors, as engineering seniors have been shown to score particularly low on deep approaches to learning and student–faculty interaction (NSSE 2003; Nelson Laird et al. 2008). These findings are also consistent with work that shows that institutions with a high percentage of departments offering both undergraduate and graduate education have lower levels of undergraduate student engagement (McCormick, Pike, Kuh, and Chen 2009).

Next we sorted the institutions by their STEM effect sizes to identify those institutions in the top one hundred on each variable that had minimal or nonexistent STEM/non-STEM differences (effect sizes greater than -0.1 and less than 0.1)—looking, in other words, for institutions where engagement was comparable for the two groups. Table 2 shows us that, with regard to Integrative and Reflective Learning, STEM seniors scored more than 0.3 standard deviations lower than non-STEM seniors in 99 percent and 98 percent of all 614 institutions in our sample, respectively. Those proportions are only slightly smaller for the top one hundred institutions. There are essentially no institutions where there is not a STEM/non-STEM difference on these scales!

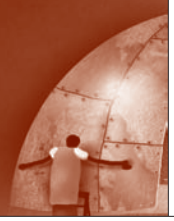
For Higher-Order Learning and Student–Faculty Interaction, most institutions in the total sample and the top one hundred have small STEM/non-STEM differences. For Active and Collaborative Learning more than half have small STEM differences, but the distributions favor STEM disciplines: that is, on this measure, STEM seniors score higher than non-STEM seniors at more institutions than the reverse. Interestingly, the top one hundred institutions were more likely to have negative STEM differences for Higher-Order Learning and less likely to have negative STEM differences for Student–Faculty Interaction. A look at table 2 with an eye toward getting an institution into the top one hundred reveals at least three possibilities: (1) pull an institution's overall average up by improving non-STEM student engagement (see the greater proportion of top one hundred institutions with negative effect sizes for Higher-Order Learning), (2) pull the overall average up by improving STEM student engagement (see the greater proportion of top one hundred institutions with positive effect sizes for Active and Collaborative Learning), and (3) increase student engagement as needed to equalize STEM/non-STEM differences (see the greater proportion of top one-hundred institutions with trivial differences for Student–Faculty Interaction).

We posit that the last option should be institutions' preferred method and that it should cut across lots of measures of student engagement. So our final task was to determine whether any institutions were in the top one hundred across multiple measures and had small STEM/non-STEM differences. Since no institutions had small differences for integrative and reflective learning, we focused on the other three measures. Only ten institutions were in the top one hundred for Higher-Order Learning, Active and Collaborative Learning, and Student–Faculty Interaction and also had small STEM/non-STEM differences across all three measures. These Engaging Ten are all private, less selective (Barron's selectivity rating of Competitive Plus or below), and Master's (6) or Baccalaureate Arts and Sciences institutions (4).

TABLE 2. DISTRIBUTION OF STEM/NON-STEM DIFFERENCES ON FIVE ENGAGEMENT MEASURES BY INSTITUTIONAL GROUPS

	DEEP APPROACHES TO LEARNING						OTHER NSSE MEASURES			
	Higher Order Learning		Integrative Learning		Reflective Learning		Active and Collaborative Learning		Student-Faculty Interaction	
STEM/non-STEM Effect Sizes	All 614 Inst	Top 100	All 614 Inst	Top 100	All 614 Inst	Top 100	All 614 Inst	Top 100	All 614 Inst	Top 100
≥0.3[a]	0%	0%	0%	0%	0%	0%	1%	1%	0%	0%
≥0.1 and < 0.3[a]	1%	0%	0%	0%	0%	0%	20%	37%	3%	3%
>-0.1 and <0.1[b]	93%	81%	0%	0%	0%	0%	70%	57%	74%	92%
> -0.3 and≤-0.1[c]	6%	19%	1%	5%	2%	8%	9%	5%	24%	5%
≤0.3[c]	0%	0%	99%	95%	98%	92%	<1%	0%	0%	0%

[a]*STEM averages are above non-STEM (notably so for effect sizes of 0.3 or greater).*
[b]*STEM and non-STEM averages are comparable.*
[c]*STEM averages are below non-STEM (notably so for effect sizes of -0.3 or less).*



ENCOURAGING RESULTS—LESSONS MOVING FORWARD

While our analyses point to some discouraging results, there are also several encouraging trends for STEM education reformers. First of all, we are excited that large fractions of top one hundred institutions on three measures—higher-order learning, active and collaborative learning, and student-faculty interaction—have minimal STEM/non-STEM differences. This indicates that at many high-performing institutions, students across fields are experiencing the benefits of an engaging educational experience. This is a signal that institutions can foster what might be called a single "culture of engagement" on campus, one that diminishes the impact of those disciplinary teachings and traditions brought in by faculty that actually hamper undergraduate engagement and learning (e.g., a preference for passive teaching methods).

Our results also suggest that the use of active and collaborative learning practices by STEM seniors may be the crowning achievement of the STEM reform movement to date. At 95 percent of the top one hundred institutions on this measure and 91 percent of all institutions, STEM senior averages are greater than non-STEM senior averages. It appears that efforts to increase the use of active and collaborative pedagogies throughout STEM fields have taken root. To further document this result, we plan analyses that will map the trend in the use of active and collaborative learning in STEM fields over the past decade.

Another encouraging result is that, with the exception of the Research Universities, all institutional types (public and private, more and less selective) are represented in the profiles of high-performing institutions. In addition, the institutions that are most engaging across multiple measures and have small STEM/non-STEM effects are private, but not elite, supporting the notion that making an institutional commitment to get undergraduate education right—across STEM and non-STEM fields—may, in the end, be more important than selectivity and the financial resources that typically accompany it.

Indeed, evidence suggests that educational experiences focused on engagement and deeper learning, as opposed to passive teaching methods and "weeding students out," achieves better outcomes and does not necessarily cost more (DeHaan 2005; Fairweather 2009). Even if such educational experiences do cost more than passive and weeding-out methods on the front end, better learning outcomes, improved satisfaction and retention, and shorter time to degree completion should offset any additional up-front investment through lower long-term costs to institutions and families and greater achievement of educational missions. Spelling out the specific costs and benefits is another area where additional work can fruitfully be carried out.

Alongside these encouraging results, however, is news that STEM seniors lag well behind non-STEM seniors in integrative and reflective learning at nearly all institutions. These approaches to learning, we and others (AAC&U 2007; National Research Council 2003) argue, are central to good scientific thought and critical components of what makes for a well-prepared college graduate. If active and collaborative learning was the area receiving most attention in the past few decades, it seems time to turn reformers' energies toward integrative and reflective activities and move our institutions toward cultures of engagement that span a spectrum of sound educational practices. Doing so may be the next step in what DeHaan refers to as the "revolution" in undergraduate STEM education. ▪

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Using Research to Bring Interactive Learning Strategies into General Education Mega-Courses

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The college-level general education (GE) curriculum in the United States can have many goals: exposing students to the breadth of human thoughts and ideas; elevating their reading comprehension, writing abilities, evaluation of information and complex systems, critical reasoning skills; and providing an understanding of and appreciation for subjects outside of their chosen field of study. Unfortunately, the majority of this learning takes place in large enrollment courses. Therefore, as educators and researchers from many fields have documented, students often emerge from our courses without a deeper understanding of, or appreciation for, our disciplines. Further, they fail to acquire the skills and abilities we have worked so hard to help them develop. How, then, can we expect these students to go out into society and successfully engage with, and help solve, the complex and critical problems that face our nation?

In the wake of the recent US financial crisis, many institutions of higher learning have faced extreme budget cuts. Due to these cuts, faculty are being asked to teach in substantially larger classes with increasingly fewer resources. At the University of Arizona this issue has manifested itself in offering mega-classes, in the performing arts center, with enrollments from 700–1,400 students.

To address the challenges of teaching large enrollment courses, we have been engaging in a series of research studies into student learning in introductory astronomy GE college courses, commonly called Astro 101. This is a very popular introductory science course. Nationally, over 250,000 students take Astro 101 courses each year, and 10 percent of all college students take an Astro 101 course during their college education. For many of these students, this GE science class will be the final science course they take for the rest of their lives. This population of students is incredibly important to our nation's well-being as they represent our future business leaders, politicians, journalists, historians, artists, and most importantly, societal leaders, parents, tax payers, voters, and teachers. The quality of education these students receive in these courses may, therefore, have a lasting impact on their scientific literacy, their attitudes toward science, and their decision whether or not to pursue a career in a STEM field. With so much at stake, it is clearly in our nation's best interests to improve the teaching and learning happening in Astro 101 classrooms.

The Astro 101 course differs from other introductory college science courses in that it is intended for students from *all* majors; it is not the prerequisite for any other course and there is no commonly agreed upon set of topics for the course—essentially the charge is to teach the universe in a semester! On a practical level, the development of curricular materials for Astro 101 is constrained by the lack of recitation sessions, labs, and teaching assistants. The lecture portion of an Astro 101 course is commonly the only time instructors meet with their students. Therefore, instructional strategies must help students resolve conceptual and reasoning difficulties without significant help from the instructor, and they must be designed for use in large lecture halls with fixed seats. Furthermore, because new strategies can require instructors to give up precious class time normally spent lecturing, teaching innovations must be relatively brief.

The Center for Astronomy Education (CAE) at the University of Arizona has three programs dedicated to improving teaching and learning in Astro 101 classrooms. Foremost has been the development of research-validated instructional strategies shown

to improve student understanding and evidenced-based reasoning abilities. With funding from NASA and the NSF, CAE has developed a national Teaching Excellence workshop series to increase instructors' understanding of collaborative learning activities, improve their pedagogical content knowledge, and elevate their implementation abilities. Over the past six years, these multiday, participation-based professional development workshops have been attended by more than two thousand instructors from all types of institutions (from research university to community college). Finally, with funding from NSF, CAE has developed a program to expand the number of instructors, postdocs, and grad students engaging in astronomy education research in their own classrooms. This program, called the Collaboration of Astronomy Teaching Scholars (CATS), has led to several nationwide research initiatives to improve the teaching and learning of Astro 101.

These CAE/CATS efforts have culminated in a multi-institutional study to assess the effectiveness of instruction in a wide range of different Astro 101 classrooms across the country. It is worth noting that these courses ranged from the extremely traditional, lecture-only format to the highly transformed classroom environment where students are engaged for approximately half of class time in sense-making discussions in collaborative learning groups involving guided-inquiry pencil-and-paper based Lecture-Tutorials and Ranking Tasks; student discourse intensive Think-Pair-Share questioning techniques using colored voting cards; and interactive-lecture methodologies focused on demonstrations and computer simulations. We want to emphasize that the instructional methodologies and research findings discussed are *not* discipline specific, and have been successfully used to transform learning in classrooms across many disciplines in the physical and life sciences. Following the presentation of the results of this study, we will discuss the programmatic and pedagogical factors involved in trying to successfully implement the same collaborative learning strategies into a mega-class of nearly 800 students at the University of Arizona.

The recently completed Astro 101 national study of nearly four thousand students at thirty-one colleges and universities involved sixty-nine class sections, taught by thirty-nine different instructors. Phase I of this research focused on the relationships between class size, type of institution, amount of course time spent using interactive learning strategies, and course-averaged student learning gains (Prather et al. 2009; Prather, Rudolph, and Brissenden 2009). Phase II of this work focused on an analysis of student responses to a fifteen-question demographic survey. A multivariate regression analysis was conducted to determine how ascribed characteristics (personal, demographic and family characteristics), achieved characteristics (academic achievement and student major), and the use of interactive learning strategies are related to student learning gains (Rudolph et al. 2010).

These studies show dramatic improvement in student learning with the increased use of interactive learning strategies even after controlling for individual and ascribed population characteristics. Classes that spent 25 percent of their class time (or more) using interactive learning strategies averaged more than twice the normalized gain scores as compared to classes that spent less than 25 percent of class time teaching interactively. Furthermore, we found no correlation between student learning gain and type of institution or class size (even in a class of almost 800 students, as we discuss in detail below). The wide range in learning gains observed for the high-interactivity classes suggests that the quality of an instructor's implementation of interactive learning strategies may well be the most important factor in determining the learning gain of a class. These research findings help to bolster the argument that faculty professional development efforts focused on how to effectively implement active learning strategies are in great need within the college teaching community. Additionally, institutional and departmental support must be provided to faculty who work to transform their courses so that their careers are not penalized for bringing proven instructional strategies into the classroom.

Perhaps most important of all our findings was that the positive effects of interactive learning strategies apply equally to men and women, across ethnicities, for students with all levels of prior mathematical preparation and physical science course experience, independent of GPA, and regardless of primary language. These results powerfully illustrate that *all* categories of students enrolled in GE science courses can benefit from the effective implementation of interactive learning strategies.

LOGISTICAL MATTERS

Centennial Hall (CH), where Astro 101 mega-classes are taught, is a venue designed for theater, dance, ballet, and orchestral performances. There are no desktops for the more than two thousand seats. The seats are fixed and don't swivel. The rows are packed very closely together, making getting to students with questions quite difficult. The lighting is much dimmer than a normal classroom. The podium, and all media and lecture controls, are located in the corner of a raised stage well above the first row of seating, far away from where you would like to stand while addressing the students. But the acoustics are fantastic! Members of CAE looked at the mega-course as a good opportunity to investigate whether findings from courses with approximately 150 students could still be achieved in this significantly larger classroom.

There were some logistical concerns we had to work through just to create a functioning classroom. Every fifth row of the class was initially blocked with caution taped to prevent students from sitting in these rows, allowing us to move easily throughout the class to assist students during collaborative group work. We had to formulate a complex flowchart, detailing where to go and what to do in order to make handing out and picking up paperwork (participation forms, homework, surveys, etc.) possible in only a few minutes.

For in-term examinations, we had to schedule Centennial Hall outside of normal class times in order to accommodate all the subtle issues of maintaining exam security and checking student IDs in a reasonable amount of time. We had to schedule a different large lecture hall (our former classroom held for 150 students) multiple times a week in order to accommodate office hours, as it is common for between 10 to 30 percent of the class to attend office hours. A zero tolerance cell phone and laptop policy was established from the start, and strictly enforced, to prevent hundreds of students from texting and using Facebook, Twitter, or YouTube during class. In addition, we chose to have multiple-choice exams, and make use of an online and auto-graded homework system, so as to reduce the number of hours needed for grading.

From a curriculum implementation standpoint, what was most challenging about this course was determining how to emulate the same vibrant and productive collaborative learning environment we had been able to foster in our 150–300 student courses. The university provided three graduate student teaching assistants (TAs). The astronomy department provided an additional graduate TA and one undergraduate astronomy major to help with grading. We knew we would need much more help to facilitate the in-class student discourse-intensive activities and to provide sufficient support in office hours. Our solution to this problem has come through what we call the Ambassador Program, a program that employs former students of the class to provide instructional help in the classroom. This program is modeled after key elements of both the Supplemental Instruction (SI) Program developed at the University of Missouri–Kansas City, and the NSF-funded Learning Assistant (LA) Model developed at the University of Colorado at Boulder. Through the Ambassador Program, former students who have demonstrated a high level of content understanding (having received an "A" in the course), and demonstrated strong communication skills, are recruited to become TAs.

IMPACTS OF THE PROGRAM

From interviews with, and evaluations by, other students in the class we have learned that these Ambassador TAs are often preferred by students over the graduate students or even the instructor when they find themselves in need of help in class or office hours. The popularity of this program is evidenced by the increased number of students who state that they are attending office hours with the sole purpose of trying to get an "A" in the course so that they can become the next semester's Ambassadors. With the Ambassador Program we have found a pedagogically sound solution to an important instructional resource issue, and elevated the conceptual understanding and science literacy of a group of nonscience majors who have become skilled and eager to share their knowledge with others, and who will carry that ability and desire into their roles as members of our society.

The broader impacts of this program are now being felt in our second year as we see the role of returning Ambassadors elevated to astronomy education researcher. A cadre of these Ambassadors have engaged in a self-directed research program to investigate the relationship between the level of correctness and coherence in students' written responses to in-class and ungraded collaborative learning activities (Lecture–Tutorials) with the students' performance on corresponding questions on exams and concept inventories. The goal is for this work to lead to a published peer-reviewed science education journal article. With this work we see the progression of participants in the Ambassador Program from high-achieving nonscience majors taking a GE course, to peer-teaching assistants within the course, to astronomy education researchers evaluating the success of the course.

The University of Arizona Ambassador Program

The Ambassador teaching assistants go through a rigorous screening process before being hired. Students are paid $8/hour for their work, including in-class teaching, holding two office hours a week, and for attending training sessions. Every week students receive three hours of intense pedagogical training to improve their understanding of key implementation and conceptual issues regarding the following week's instructional strategies and discipline content. Our Ambassador Program is quite different from many other peer instruction programs since it does not involve majors from within our discipline (astronomy), but rather students who are almost exclusively nonscience majors.

These Ambassador TAs have proven to be exceptionally talented at facilitating Socratic dialogue with students struggling through the conceptually challenging collaborative learning activities used in the "lecture" portion of our mega-classes. We believe this ability comes from the fact that the Ambassadors were recently students in the class and, therefore, have a first-hand student perspective of how the course really works. Unlike many of our astronomy and astrophysics graduate TAs, these Ambassadors share a common understanding of the metaphors and analogies one might use to engage in a discussion that would help general education students overcome learning difficulties.

To expand the opportunities for highly motivated GE students beyond the Astro 101 classroom, the college of sciences at University of Arizona (UA) has recently created a liberal arts minor in astronomy. Through this pathway, nonscience majors will be able to graduate with a degree in astronomy/science and participate in a program that directly supports STEM growth. In a recent survey approximately 10 percent of students in UA Astro 101 classes stated they are very interested in pursuing this minor. At UA alone this could result in two hundred nonscience students coming into the astronomy liberal arts minor program every year. This will represent a significant increase over the handful of students who have changed their major to astronomy over the years.

While the Ambassador Program and liberal arts minor will enhance the opportunities for a subset of the nonscience majors, the question still remains: Does the 800-student mega-course achieve its goals for the majority of students? By a number of measures, the answer is yes. Exam averages are comparable to those of the prior seven years of Astro 101 courses with enrollments of 150+ students. More important, class-averaged normalized gain scores on two different research-validated concept inventories, the Light and Spectroscopy Concept Inventory and the Stellar Properties Concept Inventory, are among the highest in the nation.

CAUTION IN THE FACE OF SUCCESS

Evidence of successful student learning in a mega-course of 800 students is cause for excitement but also concern. Given the realities of current and future college budgets, especially at state universities, it is exciting to think that we can truly educate these students in such a setting. However, the danger comes when such a finding is misused. University leadership will undoubtedly use these positive research results to defend the teaching of mega-courses to their many stakeholders. We are concerned, however, that they will also promote the creation of these courses without providing the instructional resources, and advocating for the pedagogical practices, that are necessary if one is to create an active learning environment that leads to student success.

First and foremost our results illustrate the need for instructors to move from a professor-centered to a learner-centered teaching approach that involves effective implementation of interactive learning strategies. Without this shift in the framing of the classroom, one could ask why it wouldn't be financially sounder to simply produce high-end lecture videos of the class for students to download and watch on their own time. We fear this could well be advocated as the next step.

While our research results document that students develop improved conceptual understanding and reasoning abilities related to key astronomy topics, for those of us who have broader goals for our courses, there are still many unanswered questions. For instance, does their increased understanding of astronomy last? To what extent has their understanding of the critical role science plays in our society improved? Have we helped to create citizens capable of intellectually engaging in the issues we face as a nation? The research to answer these and other questions is being pursued in many fields, including astronomy education research, but this work is in its infancy in comparison to the research results on students' conceptual understanding of the discipline. One of our goals with this work is to motivate a national conversation among GE instructors from all topics about the importance of such goals, and of the need to conduct research about how gen. ed. science courses can best accomplish these goals.

In conclusion, we wish to thank the thousands of students for all their hard work and contributions to helping us better understand how to teach and better meet their needs as learners. ▪

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Reflections on the Potential Impacts of Reports on STEM Reform

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While reflecting on progress made since the mid-1980s in transforming undergraduate science, technology, engineering, and mathematics (STEM) learning, one of my reality checks is to ask if and how any of the reports issued since that time have made a difference—and to whom?

One ancestor of these reports is the 1986 *"Neal"* report, prepared by a National Science Board task force that was charged to analyze current trends in undergraduate education and provide suggestions for action by the National Science Foundation (NSF) and the broader community of stakeholders. The report was accepted in the hope it would "…be of interest to and serve as a basis for discussion by those who are actively concerned with the quality of the Nation's colleges and universities and our country's long-term economic health," noting however that although NSF's responses to the recommendations "…will have to be devised in the context of severe budgetary pressures and large competing demands. Thus, its implementation poses a great challenge to all concerned with the quality of higher education. But, we must all take action or suffer the consequences of an ever diminishing quality in the education of the Nation's future scientists and engineers."

The impetus for the *Neal* report directly relates to its design and thus to its impact. It was timely and contextual. It analyzed what had to be done immediately, why it had to be done, and who should take what responsibility for moving forward—recognizing the complexity of the issues to be addressed. One measure of the impact of this 1986 report are the many new conversations that NSF catalyzed and supported, in an era when there was little attention to the undergraduate STEM link in the educational pipeline. A common language about *what works* in STEM learning was shaped through these conversations. Particularly within STEM disciplinary and professional communities, a communal sense began to emerge—of a collective vision, of the necessity for action, and of the benefit to be gained by attending to learning rather than teaching.

But national reports and conversations only make a difference when something happens in on a campus, when faculty and their administrative colleagues 'in the field' join forces before taking action. As reports continue to multiply, it is easy to lose focus on taking action, without intentional stepping back to consider if and how a particular report is relevant locally. This is where I think many of us who have authored reports over the years have missed an opportunity to make a visible and documentable difference at the level of the learner. Yes, the issues are complex and contextual and what works on one campus must be adapted for use in other settings; thus the translation of generic goals into actionable strategies has to happen in the field. But accountability must be integrated into the process of making reports actionable—perhaps at the level of report design, and certainly through its dissemination.

For example, what difference might it make—to students, faculty, and the larger campus community—if conversations were sparked by the straightforward goals set forth in 1989 by Sigma X that students have easy access to:

- instruction that generates enthusiasm and fosters long-term learning
- a curriculum that is relevant, flexible, and within their capabilities
- a human environment that is intellectually stimulating and emotionally supportive
- a physical environment that supports the other three dimensions.

As the articles in this issue of *Peer Review* make clear, the reforms PKAL promotes have begun to make headway, but still face formidable obstacles. Maybe it is time for all of us to stop writing reports and start assessing institutional progress in advancing "what works." The new alliance between PKAL and AAC&U comes at an opportune moment—bringing faculty and leaders together to tackle the hard work that still lies before us. ▪

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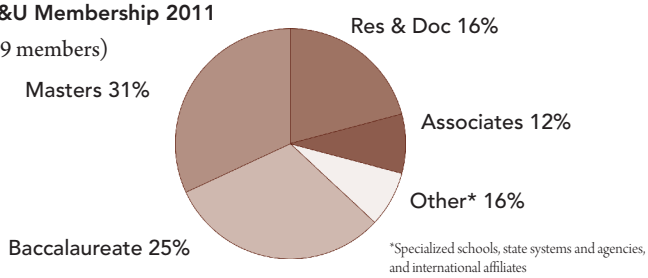

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