ACHIEVING SYSTEMIC CHANGE

A SOURCEBOOK FOR ADVANCING AND FUNDING UNDERGRADUATE STEM EDUCATION

The Coalition for Reform of Undergraduate STEM Education

Edited by Catherine L. Fry, Ph.D.

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We would also like to thank the authors of commissioned white papers that served as stage-setting documents on the topics around which the workshop discussions were centered. A list of the authors can be found on page 26. The full text of the white papers can be found at www.aacu.org/CRUSE.

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WE CAN MAKE EFFECTIVE STEM TEACHING THE NORM

This sourcebook is intended as a useful resource for all those who have a stake in creating STEM solutions for US society. It addresses the rationale for investing in systemic change throughout higher education, identifies critical areas for investment, and provides pointers to key reports and current STEM education reform efforts.

Decades of national investment in research on learning have yielded a rich array of evidence-based, high-impact teaching practices. This represents a major and ongoing achievement of efforts to advance STEM reforms in undergraduate education. Yet research also shows disappointingly little implementation of these practices in undergraduate classrooms. What will it take to align teaching practices with what we know about how students learn, and how to draw students in and encourage persistence for all?

The key, we believe, will come when faculty members, campus leaders, and funders work together to make effective practice the norm rather than the exception. Campus leaders need to set clear goals to make effective practice pervasive—goals for institutional leadership and goals for departmental progress.

Philanthropy can play a key strategic role. One of the most highly leveraged actions a funder can take is to oblige any institution that applies for funds to explain and document what they are doing to achieve a student learning–centered institutional culture. Whatever the scale of the individual projects being funded, or the specific mission and interests of the funding entity, it would be game changing if funders called for this information.

The development of frameworks for institutional change, and of new approaches to documenting faculty practices and attitudes, now allows institutions to provide more readily such data. Every call for proposals that requires addressing institutional culture encourages institutions to move toward more systemic reform, allowing funders to help set the tone for sustained change.

We hope this sourcebook will prompt the next level of strategic leadership, both on campus and from philanthropy.

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WHY SYSTEMIC REFORM
CAN NO LONGER WAIT

In the United States, fewer than 40 percent of the students who enter college with the intention of majoring in a STEM (science, technology, engineering, and mathematics) field complete a STEM degree. Most students who leave STEM fields switch to non-STEM majors after taking introductory science, math, and engineering courses. A recent report on undergraduate STEM education from the President's Council of Advisors on Science and Technology[1] (PCAST) cites "uninspiring" introductory courses and an unwelcoming atmosphere from faculty as major factors contributing to attrition from STEM fields.

The loss of talent from STEM fields is particularly alarming given the current US economic climate. Although the worst recession this country has experienced since World War II officially ended in June 2009, its effects still linger today. While the nation struggles to strengthen the economy, the educational capacity of our country continues to decline. Data from the Organisation for Economic Co-operation and Development show that in 2009, our nation ranked fifth for postsecondary attainment for citizens ages 55 to 64, but only sixteenth for those ages 25 to 34 (see http://www.oecd.org/statistics/). Trends in US educational performance are even more concerning for STEM fields: fifteen-year-olds rank twenty-sixth in math and twenty-first in science among their peers in other industrialized countries, with no significant change in performance since 2000.[2]

FEWER THAN 40 PERCENT of the students who enter college with the intention of majoring in a STEM field ***COMPLETE A STEM DEGREE.***

Changing Demographics Will Likely Exacerbate the Loss of Talent from STEM Fields

Minority populations, according to the National Assessment of Educational Progress 2013 survey, have a performance gap in math as early as fourth grade. Furthermore, 2013 Census Bureau data tell us that minorities are graduating from high school at a lesser rate, and those who do complete high school are less likely to immediately enroll in a two-year or four-year institution. The data also tell us that they are even less likely to become STEM majors, and these effects are multiplied for women. These trends are made even more troubling in light of projected race/ethnic shifts in the US population.

[1] President's Council of Advisors on Science and Technology (PCAST), *Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics* (Washington, DC: PCAST, 2012), http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_2-25-12.pdf.

[2] Organisation for Economic Co-operation and Development (OECD), *PISA 2012 Results in Focus: What 15-Year-Olds Know and What They Can Do with What They Know*, (Paris: OECD, 2013), http://www.oecd.org/pisa/keyfindings/pisa-2012-results.htm.

20 PERCENT of jobs ***REQUIRE "HIGH KNOWLEDGE"*** in STEM; ***MANY MORE REQUIRE SOME PROFICIENCY*** in STEM.[4]

According to 2008 data from the US Census Bureau, by the middle of the twenty-first century the population group we now term as the "minority" is forecast to outnumber the current majority group. In order to bring about the systemic change required for widespread improvement in STEM education, the nation must make an investment in STEM success for all students, especially those from low-income backgrounds and first-generation college students.

Workforce Demands for STEM Jobs Are Not Being Met

Further clouding the outlook for STEM are the impending retirements of baby boomers, who hold nearly a quarter of STEM jobs requiring a bachelor's degree or higher.[3] As highly educated Americans retire from the workforce, the nation will rely on young Americans to improve our global standing and spur our economic recovery. Meanwhile, American students are lagging behind international peer groups and turning away from science and math, even though STEM jobs in the United States comprise close to one-fifth of all occupations.[4] Furthermore, jobs in these fields are projected to grow 26 percent by 2020[5], making STEM fields one of the fastest-growing occupation clusters in the country. Close to two-thirds of these STEM jobs will require at least some postsecondary education.[3] Currently, too few students are both sufficiently proficient and interested in STEM to meet US workforce demands.[6]

In the past, the United States has relied on foreign-born workers to meet demands for STEM jobs, but reliance on foreign nationals makes our economy and national security vulnerable.[7] While current and proposed immigration reforms may make it easier for foreign-born STEM professionals to stay in the United States, the global market is shifting so that China, India, and other countries are able to compete on wages to attract top STEM talent.[7] Continuing to rely on foreign-born talent is therefore not a long-term strategy for economic growth.

All Students Benefit from Improved STEM Education

While some recent reports have called into question the so-called US "STEM crisis,"[8,9] framing the discussion purely in terms of STEM majors or STEM jobs overlooks the need for a STEM-literate society and STEM-competent workers in a variety of fields. Improved STEM education will serve all students regardless of major, as some STEM coursework is typically required for graduation. While the Brookings Institution estimates that 20 percent of jobs require "high knowledge" in STEM; many more require some proficiency in STEM.[4] Although STEM knowledge is commonly perceived as being highly specialized, it is both transferable and useful in contexts outside the traditional STEM disciplines and occupations.[3] The US Department of Commerce found that people with STEM degrees who go into non-STEM jobs earn 12 percent more than those who don't hold degrees in STEM,[10] emphasizing that employers value STEM knowledge well beyond often narrowly defined "STEM jobs." Other reports have underscored the broad need for skills associated with scientific literacy, including quantitative and information literacy, inquiry, analysis, and critical thinking, as essential to the democratic vitality of the country.[11]

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[3] Anthony P. Carnevale, Nicole Smith, and Michelle Melton, *STEM: Science, Technology, Engineering, Mathematics* (Washington, DC: Georgetown University Center on Education and the Workforce, 2011).

[4] Jonathan Rothwell, *The Hidden STEM Economy* (Washington, DC: Brookings Institution, 2013).

[5] Anthony P. Carnevale, Nicole Smith, and Jeff Strohl, *Recovery: Job Growth and Education Requirements through 2020* (Washington, DC: Georgetown University Center on Education and the Workforce, 2013).

[6] Business Higher Education Forum (BHEF), *BHEF Research Brief: Creating the Workforce of the Future: The STEM Interest and Proficiency Challenge* (Washington, DC: BHEF, 2011).

[7] President's Council of Advisors on Science and Technology, *Engage to Excel.*

[8] Robert N. Charette, "The STEM Crisis Is a Myth," *IEEE Spectrum*, August 30, 2013, accessed June 24, 2013, http://spectrum.ieee.org/at-work/education/the-stem-crisis-is-a-myth.

[9] Hal D. Salzman, Daniel Kuehn, and B. Lindsay Lowell. *Guestworkers in the High-Skill US Labor Market* (Washington, DC: Economic Policy Institute, 2013).

[10] David Langdon, et al., *STEM: Good Jobs Now and for the Future* (Washington, DC: US Department of Commerce, 2011).

[11] Association of American Colleges and Universities (AAC&U), *College Learning for the New Global Century: A Report from the National Leadership Council for Liberal Education and America's Promise* (Washington, DC: AAC&U, 2007).

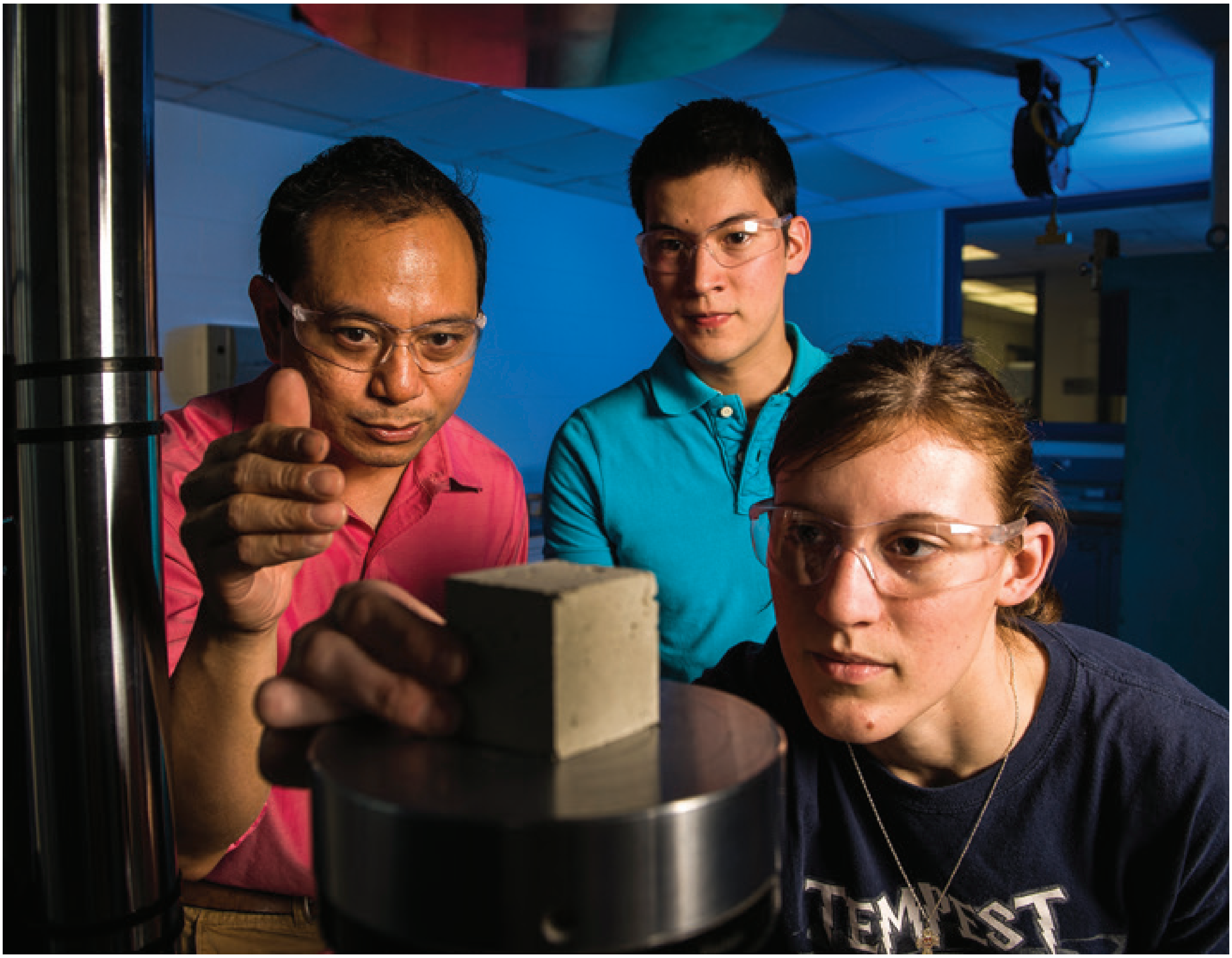
Investing for Maximum Impact

Promoting systemic change requires investing in broad use of high-impact teaching practices that engage students directly and draw in a student body that is fully representative of the diversity of our population. Achieving systemic change relies on cultural shifts that will require adequate time, resources, and coordination. *This is a propitious opportunity for funders to strategically coordinate their varied missions and approaches in order to maximize their collective impact on STEM higher education.*

This alignment cannot occur in a vacuum. It is essential that funders, change agents, and policy makers are well informed of their mutual activities, and that they mutually shape their actions in order to effect systemic and lasting change.

The recommendations presented in this sourcebook are organized under seven overarching goals:

1. ***Promote systemic change in institutional culture***
2. ***Support department-wide implementation of evidence-based practices***
3. ***Support faculty development and leadership***
4. ***Support continued examination and adoption of successful curricular approaches***
5. ***Expect institutions to address systemic change through measurable indicators and evaluation***
6. ***Expect institutions to plan for sustained change***
7. ***Strengthen teacher preparation programs***



BUILDING INSTITUTIONAL CAPACITY
TO ADVANCE SYSTEMIC CHANGE

It is crucial to establish an institutional culture that is committed to excellence and inclusion in STEM education, including the pervasive use of high-impact, evidence-based practices and an institution-wide commitment to student success. Rhetoric about valuing teaching is not sufficient when it is not reflected in institutional policies and practices.

Research has demonstrated that simply informing faculty of evidence-based approaches does not necessarily result in changes to their practices.[12,13] Efforts to change teaching practices are more likely to succeed if they recognize the cultural and organizational norms of the department and institution and work to address the norms that pose barriers to changing teaching practices.[14,15]

A frequently cited barrier to improving faculty teaching practices is the faculty reward structure for salary increases, and tenure and promotion policies that prioritize research over teaching. While progress has been made in recognizing scholarly research on pedagogy, the intellectual work of teaching itself must also be rewarded.

No matter what process ultimately carries curricular innovations forward, institutional policies and practices must be addressed in order to sustain change.

All efforts to change faculty teaching practices need to take into account the underlying change strategies, and the associated strengths and weaknesses of those strategies (fig. 1).

Goal 1. Promote systemic change in institutional culture

When an institution's mission includes commitment to excellence in STEM education, the institution should ensure that its policies, structures, and practices facilitate the achievement of this strategic goal. Engaging governing boards in these discussions helps ensure that policies and practices align with the institutional mission to prioritize excellence in STEM education.

Funders should encourage or require teams planning new initiatives to explicitly consider the institution-level policy implications relative to sustaining a successful initiative. Faculty should be aware of the link between their efforts and their institution's policies. Establishing such a "policy to consider policy implications" might motivate changes in structures and conversations along the way that increase the possibility of persistence.

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[12] Charles Henderson and Melissa H. Dancy, *Increasing the Impact and Diffusion of STEM Education Innovations,* white paper commissioned for the Characterizing the Impact and Diffusion of Engineering Innovations Forum (February 7–8, 2011).

[13] National Research Council, *Promising Practices in Undergraduate Science, Technology, Engineering, and Mathematics Education: Summary of Two Workshops,* ed. N. R. Nielsen (Washington, DC: National Academies Press, 2011).

[14] National Research Council, *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering* (Washington, DC: National Academies Press, 2012).

[15] Jo Handelsman, et al., "Scientific Teaching," *Science 304* (2004): 521–522.

Aspect of System to be Changed	Intended Outcome: Prescribed	Intended Outcome: Emergent
Individuals	**DISSEMINATING CURRICULUM AND PEDAGOGY** ***Change Process*** Tell/teach individuals about new teaching practices and encourage their use. ***Examples*** Dissemination/training	**DEVELOPING REFLECTIVE TEACHERS** ***Change Process*** Encourage/support individuals to develop new teaching practices. ***Examples*** Reflective practice, curriculum development
Environments and Structures	**ENACTING POLICY** ***Change Process*** Prescribe new environmental features that require/encourage new teaching practices. ***Examples*** Policy change, strategic planning	**DEVELOPING SHARED VISION** ***Change Process*** Empower/support stakeholders to collectively develop environmental features that encourage new teaching practices. ***Examples*** Institutional transformation

Figure 1. Four categories of change strategies

Adapted from: Henderson, Charles, Andrea Beach, and Noah Finkelstein. 2011. "Facilitating Change in Undergraduate STEM Instructional Practices: An Analytic Review of the Literature." Journal of Research in Science Teaching *48 (8): 952–984.*

Funders should support projects that develop organizational change strategies directed toward excellence in undergraduate STEM education. These projects should acknowledge diverse institutional types, missions, and capacities for change, with attention to resource limitations. Projects should also target reform at different levels of the institution: department, division, entire institutions, and across institutions. *Investing in organizational change and monitoring processes rooted in data and accountability will create better-sustained initiatives.*

Recommendation 1.1. Cultivate leadership development for sustainable change

Leadership is required to catalyze, implement, and sustain large-scale reform efforts. Institutions typically do not have programs for developing leaders, either because of lack of capacity or funding. Engaging, educating, and empowering formal leaders (e.g., chairs, deans, provosts, presidents, boards) is important for developing sustainable shifts at the institutional level that support improved learning and student success in STEM education. Such leadership development could occur through institutes to train leaders at different levels. These institutes should focus on development of individual leadership skills as well as skills and knowledge required to lead teams focused on institutional transformation.

Recommendation 1.2. Address the faculty reward system

The faculty reward system must recognize and reward efforts by faculty members to use evidence-based pedagogy. Assessment of student learning and achievement of program outcomes is another area where reward and recognition is lacking.

In addition, interdisciplinary work is not always recognized by tenure and promotion committees, and institutional support for faculty engaging in multi-disciplinary education research is sometimes uncertain.

There is a need to fund national summits focused on the development of new systems and approaches for faculty incentives, including promotion and tenure, and faculty development programs that are organized to achieve optimal impact on strengthening teaching and learning. Funders should consider supporting team-based institutes to bring key stakeholders together around reforming reward and evaluation structures. These institutes might be convened by higher education associations for greater leverage.

Recommendation 1.3. Address learning spaces as critical

Learning occurs within the context of the built environment, and increasing the use of evidence-based practices requires consideration of the learning spaces in which faculty and students are situated. A variety of evidence-based practices rely on group discussion, teamwork, and faculty–student interaction that can be challenging in traditional lecture rooms. Recent efforts to think more deliberately about learning spaces include an emphasis on those that are dynamic, encourage interaction, and support students in constructing their own learning. A variety of resources on planning and assessing effective learning spaces are available from the Learning Spaces Collaboratory (see http://pkallsc.org/Resources).

Recommendation 1.4. Plan for and evaluate appropriate uses of instructional technology

Use of student response systems (e.g., clickers) has become routine in large classes over the last decade, as have electronic homework and the posting of materials for study before and after class. It is clear that online instruction can provide a set of tools for mapping and delivering the content and core ideas of a field, with new possibilities for dynamic representation of concepts and processes. Online tools can also provide both students and teachers with real-time feedback on mastery of content. There has been a recent proliferation of massive open online courses (MOOCs), but their ability to serve the populations not well served by campus-based education is still in question. In order to optimize its effectiveness, online coursework still needs human scaffolding for encouragement and mentoring, and to teach discourse, argumentation, and research. "Flipped" classrooms are already taking advantage of a blended model of both online content delivery and face-to-face interaction.

At this stage, it is critical for both funders and campus leaders to support thoughtful investigation and implementation of instructional technology, with careful attention to its impact on student outcomes across the populations to be served.

Recommendation 1.5. Institutionalize faculty development efforts

Many funders and campus-based centers are already engaged in supporting training for new faculty. We encourage funders to support faculty development programs that specifically address STEM education priorities, including the development of faculty across career stages and the preparation of doctoral students and post-docs to be effective teachers. Funders should also support research on centers of teaching and learning to discover the characteristics that allow them to support a change agenda, particularly in the context of STEM education. This research should take into account institutional contexts and faculty perceptions and behaviors.

Crucial to wide implementation is the endorsement and monitoring of this recommendation by highly regarded national organizations such as the American Association for the Advancement of Science (AAAS), the Association of American Colleges & Universities (AAC&U), the Association of American Universities (AAU), the Association of Public and Land-grant Universities (APLU), and others. Campuses should create plans for sustaining the faculty development programs over the long term.

Recommendation 1.6. Call for greater transparency of financial models

Accounting systems are not typically set up to capture and leverage the institutional value of improvements in student success at the course and program level. This leads to improvement efforts being seen only in terms of their cost. A better understanding of the nuanced accounting methods that capture the value of success could be a significant lever for change.

RECOMMENDED RESOURCES

Henderson, C., N. Finkelstein, and A. Beach. 2010. "Beyond Dissemination in College Science Teaching: An Introduction to Four Core Change Strategies." *Journal of College Science Teaching* 39 (5): 18–25.

National Research Council. 2012. *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering.* Washington, DC: National Academies Press.

President's Council of Advisors on Science and Technology. 2012. *Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics.* Available at: http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_2-25-12.pdf.

RELATED PROJECTS AND PROGRAMS

CIRTL

The Center for the Integration of Research, Teaching, and Learning (CIRTL) uses graduate education as the leverage point to develop the next generation of STEM faculty who are committed to implementing and advancing effective teaching practices for diverse student audiences. The goal of CIRTL is to improve STEM learning for all students at every college and university, and thereby to increase both diversity in STEM fields and the STEM literacy of the nation. The CIRTL network comprises a learning community of twenty-three diverse research universities mutually engaged in the deliberate, systematic, and reflective use of research methods to develop and implement evidence-based teaching practices. See http://www.cirtl.net/.

SCALE-UP

The SCALE-UP (Student-Centered Active Learning Environment with Upside-down Pedagogies) approach originated at North Carolina State University in large-enrollment physics courses and has been adopted by a diverse array of disciplines and institutions, including community colleges and high schools. SCALE-UP encourages active learning through its approach to learning spaces. Students are seated at round tables to facilitate teamwork, while the instructor moves freely among the groups to provide feedback and encourage dialogue. The "upside-down" pedagogies require students to engage with the content outside of the formal classroom and use class time for discussions and collaborative work. The SCALE-UP approach has been shown to improve conceptual understanding and problem solving, particularly for students underrepresented in the STEM disciplines. See http://scaleup.ncsu.edu/.

Center for STEM Learning at the University of Colorado Boulder

The Center for STEM Learning at the University of Colorado Boulder integrates more than seventy-five programs and projects in STEM education. The center seeks to provide an infrastructure of institutional support for the transformation of STEM education. The center integrates an interdisciplinary community of scholars, promotes and sustains reform efforts, advocates for diversity and access, advances professional development efforts, and supports education research within and across STEM fields. Additional activities include working to establish the Chancellor's Awards for Excellence in STEM Education. These awards support faculty and graduate student engagement in innovative research on student learning and implementation of evidence-based pedagogies in STEM courses and programs. See http://www.colorado.edu/csl/.

TIDES

The Teaching to Increase Diversity and Equity in STEM (TIDES) initiative supports the development of models for broader institutional change for the advancement of evidence-based and culturally competent teaching in STEM fields, particularly in the computer and information science domains. Supported by the Leona M. and Harry B. Helmsley Charitable Trust and organized by the Association of American Colleges and Universities, TIDES aims to (1) develop and implement curricula that will enhance underrepresented student interest, competencies, and retention rates, and (2) empower STEM faculty to adopt culturally sensitive pedagogies and sustain the practices required for inclusive STEM teaching. See http://www.aacu.org/pkal/tides.

OVERCOMING THE BARRIERS
TO WIDESPREAD CHANGE IN FACULTY PRACTICES

Recent movements emphasizing the importance of evidence-based pedagogy have made great strides in increasing faculty awareness of these practices. In general, faculty are aware of evidence-based practices and are interested in using them.[16,17] However, while faculty awareness may be necessary for change, it is not sufficient.

It is crucial to recognize that most faculty members are situated within structures that tend to favor traditional instruction. There are powerful situational impediments that even a highly motivated individual may face. Potential barriers[18] to the adoption of evidence-based practices include

- lack of time;
- expectations of broad content coverage;
- large class sizes;
- limitations of the physical teaching space; and
- student attitudes and expectations.

Reform efforts must acknowledge these challenges and provide strategies both for recognizing them and coping with them.

Barriers are often exacerbated for non-tenure-track faculty, who currently constitute more than two-thirds of faculty at nonprofit institutions.[19] Non-tenure-track faculty frequently lack access to campus resources, professional development, office space, and a host of other benefits available to tenure-track faculty. Increasing the broad use of evidence-based pedagogy will therefore require careful consideration of the changing nature of the professoriate.

Adoption of effective practices can be encouraged by

- providing easily modifiable materials;
- making sure faculty understand not only what works but why it works, so that adaptations of a given method remain aligned with research about its effectiveness; and
- recognizing the importance of social connections through workshops and other peer interactions, as these have been shown to lead to greater adoption than evidence presented via the literature.[20]

Professional development efforts for faculty typically involve isolated, intensive workshops where the main goal is to change the beliefs and instructional practices of individual faculty.[21] However, individual workshops generally do not bring about the desired effects on teaching.[22] Lasting change will require a sustained effort with supporting structures and expertise on

[16] Maura Borrego, Jeffrey E. Froyd, and T. Simin Hall, "Diffusion of Engineering Education Innovations: A Survey of Awareness and Adoption Rates in U. S. Engineering Departments," *Journal of Engineering Education* 99 (2010): 185–207.

[17] Melissa Dancy and Charles Henderson, "Pedagogical Practices and Instructional Change of Physics Faculty," *American Journal of Physics* 78 (2010): 1056–1063.

[18] Charles Henderson and Melissa H. Dancy, "Barriers to the Use of Research-based Instructional Strategies: The Influence of Both Individual and Situational Characteristics," *Physical Review Special Topics–Physics Education Research* 3 (2007): 1–14.

[19] Adrianna Kezar, "The New Ecology of Higher Education: The Changing Faculty," WASC Concept Papers, Second Series: The Changing Ecology of Higher Education and Its Impact on Accreditation (January 2013), 1–7, https://wascsenior.app.box.com/s/6lxkjmfeb9eu6i7nzn82.

[20] Henderson and Dancy, *Increasing the Impact and Diffusion of STEM Education Innovations.*

[21] Mark R. Connolly and Susan B. Millar, "Using Workshops to Improve Instruction in STEM Courses," *Metropolitan Universities* 17 (2006): 53–65.

[22] Diane Ebert-May, et al., "What We Say Is Not What We Do: Effective Evaluation of Faculty Professional Development Programs," *BioScience* 61 (2011): 550–558.

campus or in easily accessed networks. In order to achieve the greatest improvement in student learning outcomes, the larger group of unengaged STEM faculty should be encouraged to adopt any form of pedagogy that increases student engagement.[23] A concentrated effort to support them while they learn new methods and adopt or adapt them for continued use is critical.

Goal 2. Support department-wide implementation of evidence-based practices

Recommendation 2.1. Identify and support departmental exemplars

Departmental commitment to STEM reform is crucial to improved learning outcomes, enhanced visibility of STEM education, and long-term sustainable change. Funders could identify departmental exemplars to serve as demonstration sites that address leadership roles in the department, faculty development, curriculum and course development, assessment of student learning, and the value of teaching in faculty personnel decisions. Several national projects are already taking this approach (e.g., PULSE and the AAU STEM Initiative; see pages 12 and 21, respectively). Lessons learned from these and other departmental approaches should be used to expand national reforms in different institutional contexts.

Successful short-term outcomes include departmental implementation of strategies to improve undergraduate STEM education. Long-term outcomes include widespread curriculum and instructional change across departmental faculty incorporating evidence-based teaching and learning, hiring practices and promotion and tenure criteria modified in light of these reforms, and evidence of impact on student learning. Regional and national efforts should include working directly with departments to effect change.

Goal 3. Support faculty development and leadership

Recommendation 3.1. Cultivate faculty leadership development via institutes

Although leadership is required to catalyze, implement, and sustain large-scale reform efforts, institutions typically do not have programs for developing leadership for individuals not in formal leadership positions. Funders should support leadership institutes, perhaps modeled on ongoing efforts such as Project Kaleidoscope's Summer Leadership Institute (see page 12) or the Summer Institutes on Undergraduate Education offered through a partnership between the National Academy of Sciences and the Howard Hughes Medical Institute. These institutes should focus on development of individual faculty leadership skills as well as skills required to lead teams focused on institutional transformation. Faculty attending institutes could form a national network of STEM leaders to advance inter-campus collaborations. Incentives for non-tenure-track faculty to engage in these activities should also be explored.

Recommendation 3.2. Support faculty learning communities

Faculty learning communities now represent a well-established approach that has been successful in changing faculty practices and attitudes toward teaching and in improving student learning outcomes. These communities can provide ongoing support for faculty as they work to improve their teaching and may be organized around a particular cohort of faculty (e.g., junior or senior faculty) or around topics of mutual interest (e.g., a course reform project or assessment practices). Faculty learning communities supplement and reinforce the outcomes of participating in individual workshops or institutes through ongoing reflection, mutual support, and collaboration.

Recommendation 3.3. Support mid-career/senior faculty as champions and change agents

Seasoned faculty members who are experienced teachers or innovators can be powerful champions for change, especially if they carry institutional clout or political capital. While junior faculty are often looked to as those with fresh energy, perspectives, and motivation, senior faculty should also be included and supported in reform efforts. Many professional development opportunities are geared toward newer faculty, but programs that include mid-career/senior faculty should also be supported.

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[23] James Fairweather, *Linking Evidence and Promising Practices in Science, Technology, Engineering, and Mathematics (STEM) Undergraduate Education* (Washington, DC: The National Academies National Research Council Board of Science Education, 2008), http://www.nsf.gov/attachments/117803/public/Xc--Linking_Evidence--Fairweather.pdf.

RECOMMENDED RESOURCES

American Association for the Advancement of Science. 2011. *Vision and Change in Undergraduate Biology Education: A Call to Action.* Washington, DC: American Association for the Advancement of Science. http://visionandchange.org/finalreport.

Cox, M. D. 2004. "Introduction to Faculty Learning Communities." *New Directions for Teaching and Learning* 97: 5–23.

Fairweather, J. 2008. *Linking Evidence and Promising Practices in Science, Technology, Engineering, and Mathematics (STEM) Undergraduate Education.* Washington, DC: The National Academies National Research Council Board on Science Education. http://www.nsf.gov/attachments/117803/public/Xc--Linking_Evidence--Fairweather.pdf.

RELATED PROJECTS AND PROGRAMS

PULSE

Recognizing the need to improve undergraduate biology education, the *Vision & Change in Undergraduate Biology Education* initiative put forth recommendations for collective action that focus on student-centered pedagogies, core competencies, and campus-wide commitment to change. Following these recommendations, the Partnership for Undergraduate Life Sciences Education (PULSE) is dedicated to department-level implementation of the *Vision & Change* recommendations. The mission of PULSE is to transform learning in the life sciences by advancing department-wide use of evidence-based pedagogies. To this end, the PULSE community has developed a framework for change intended to guide departments through the iterative process of transformation. See http://www.pulsecommunity.org/.

Project Kaleidoscope: Summer Leadership Institutes

Project Kaleidoscope's Summer Leadership Institutes provide both early and mid-career STEM faculty with the theory and practice required to effectively manage the politics of change and contribute to national STEM higher education reform efforts. Each institute matches participants with mentors who are nationally recognized leaders in STEM higher education and contribute first-hand experience in institutional change leadership at the local and national levels. Mentors work with participants both during and after the institute to shape a personal agenda for leadership and an institutional action plan. Evidence-based pedagogies are modeled in the institute's activities, including case studies, role-playing, reflection, collaborative problem-solving exercises and experiential learning. To date, over 40 percent of institute alumni hold positions of leadership on their home campus. See https://www.aacu.org/pkal/events.

SPIN-UP

The Strategic Programs for Innovations in Undergraduate Physics (SPIN-UP) project aims to transform undergraduate physics programs. SPIN-UP views the department as the critical unit for change, and works with teams of faculty members and campus leaders to analyze the current departmental situation and strategize how to implement sustainable change. In addition to advancing student-centered pedagogies, SPIN-UP places emphasis on recruiting, retention, mentoring, informal faculty-student interactions, and opportunities to engage in research, among other factors that support student success. Recognizing the important role of two-year colleges, SPIN-UP has also identified the qualities of exemplary physics programs at two-year colleges from which a large number of minorities and women enter STEM programs at four-year colleges or universities. See http://www.aapt.org/Programs/projects/spinup/.

MAKING STUDENT SUCCESS
A SHARED PRIORITY

Years of extensive research on teaching and learning have resulted in a significant understanding of effective practices that improve student learning outcomes. While much of this research has taken place within individual disciplines, the core characteristics of effective pedagogies are not discipline-dependent. These pedagogies, such as problem-based learning, peer-led team learning, and process-oriented guided inquiry learning, share an emphasis on engaging students in active learning. Many educational interventions in STEM involve multiple approaches, which can enhance student performance and persistence.[24]

While all students stand to benefit from evidence-based practices, student access can vary considerably. Students in private institutions tend to have greater access to one or more effective practices during their coursework than students in public institutions.[25]

Traditionally underserved students also have, on average, less exposure to these practices, which is particularly troubling given that these very students benefit disproportionately from their use.[24,25]

Recent calls to improve undergraduate STEM education have emphasized the importance of the first two years of undergraduate coursework on retention and recruitment of students in STEM fields.[26] Most students who leave STEM do so after their first year, and the most significant influence on this decision is poor teaching.[27] Active learning has been demonstrated to improve student performance and pass rates in STEM courses,[28] and to retain more STEM majors compared to traditional, lecture-based approaches.[29,30]

Large-enrollment, foundational STEM courses therefore represent a key opportunity to engage students in the kind of learning that encourages them to persist in STEM fields. Student-centered pedagogies afford greater opportunities

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[24] Bettina J. Huber, *Does Participation in Multiple High Impact Practices Affect Student Success at Cal State Northridge? Some Preliminary Insights* (Northridge, CA: California State University–Northridge Office of Institutional Research, 2010). Retrieved from http://www.calstate.edu/engage/documents/csun-study-participation-in-multiple-high-impact-practices.pdf.

[25] George D. Kuh, *High-Impact Educational Practices: What They Are, Who Has Access to Them, and Why They Matter* (Washington, DC: Association of American Colleges and Universities, 2008).

[26] President's Council of Advisors on Science and Technology, *Engage to Excel.*

[27] Elaine Seymour and Nancy M. Hewitt, *Talking About Leaving: Why Undergraduates Leave the Sciences* (Boulder, CO: Westview Press, 1997).

[28] Scott Freeman, et al., "Active Learning Increases Student Performance in Science, Engineering, and Mathematics," *Proceedings of the National Academy of Sciences* (2014): 1–6.

[29] American Society for Engineering Education, *Going the Distance: Best Practices and Strategies for Retaining Engineering, Engineering Technology and Computing Students* (Washington, DC: American Society for Engineering Education, 2012).

[30] Marie Kendall Brown, et al., *Teaching for Retention in Science, Engineering, and Math Disciplines: A Guide for Faculty* (Ann Arbor, MI: University of Michigan Center for Research on Teaching and Learning, 2009), http://www.crlt.umich.edu/sites/default/files/resource_files/CRLT_no25.pdf.

Large-enrollment, ***FOUNDATIONAL STEM COURSES*** therefore ***REPRESENT*** a ***KEY OPPORTUNITY*** to ***ENGAGE STUDENTS*** in the kind of learning that encourages them to ***PERSIST IN STEM*** fields.

for meaningful faculty-student interaction than traditional lectures. Faculty behaviors (e.g., signaling an inclusive and welcoming atmosphere, demonstrating enthusiasm, and encouraging student collaboration through cooperative learning) play a significant role in improving student engagement in introductory STEM courses and persistence after the first year,[31] especially for underrepresented groups.[32]

Another well-established contributor to student success in STEM is participation in authentic research experiences. The benefits of these experiences include improving attitudes about STEM, enhancing communication and critical analysis skills, learning about STEM careers, and achieving greater understanding of the scientific process, among others.[33,34] Research experiences in particular help to shape identification with STEM fields and to both socialize and prepare students for scientific careers.[35] The PCAST report recently underscored the importance of research experiences, emphasizing that it is critical to engage students in research during their first two years through both widespread integration of research into the introductory STEM curricula, and increased opportunities for students to participate in faculty research.[36]

Increased use of evidence-based practices will benefit more than just the students who choose to stay in STEM majors. For some students, an "introductory" STEM course may be their only STEM course. A vital, economically robust society depends on a scientifically literate citizenry who understands how science works, the nature of evidence and argumentation, and the application of scientific contexts to ill-defined, real-world problems. Higher education must therefore ensure that all students have access to STEM courses taught via evidence-based, student-centered practices.

Goal 4. Support continued examination and adoption of successful curricular approaches

Sustained curricular change requires commitment at the institutional and departmental levels. While a great deal is known about interventions at the course level, investment is needed to situate these practices in the context of institutional change. Ongoing efforts should reflect recommendations to focus on the first two years of the STEM curriculum.

Recommendation 4.1. Support evidence-based pedagogy across all first- and second-year courses

Given the time and practice it takes to plan and implement effective student-centered approaches, and the time it takes for students to adjust to these new pedagogies, institutions should be supported in using the same or similar approaches in all first- and second-year courses and linking pedagogies across programs.

Recommendation 4.2. Support research on the characteristics of successful research experiences

Research experiences are extremely valuable for retention, motivation, and integration of learning. Opportunities to engage in authentic research should be built into early STEM courses. Funders should support research on the importance of the timing, frequency, and nature of research experiences, including the relative roles of research as part of coursework compared to research conducted in faculty labs.

Recommendation 4.3. Support integration of twenty-first-century skills across the entire curriculum

Shifts in employment trends toward more interdisciplinary work increase the need for twenty-first-century skills such as communication and teamwork. Funders should encourage

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[31] Josephine A. Gasiewski, et al., "From Gatekeeping to Engagement: A Multicontextual, Mixed Method Study of Student Academic Engagement in Introductory STEM Courses," *Research in Higher Education* 53 (2011): 229–261.

[32] Laura W. Perna, et al., "Identifying Strategies for Increasing Degree Attainment in STEM: Lessons from Minority-Serving Institutions," *New Directions for Institutional Research* 148 (2010): 41–51.

[33] David Lopatto, "Undergraduate Research Experiences Support Science Career Decisions and Active Learning," *CBE Life Sciences Education* 6 (2007): 297–306.

[34] Elaine Seymour, et al., "Establishing the Benefits of Research Experiences for Undergraduates in the Sciences: First Findings from a Three-Year Study," *Science Education* 88 (2004): 493–534.

[35] Heather Thiry, Sandra L. Laursen, and Anne-Barrie Hunter, "What Experiences Help Students Become Scientists?: A Comparative Study of Research and Other Sources of Personal and Professional Gains for STEM Undergraduates," *The Journal of Higher Education* 82 (2011): 357–388.

[36] President's Council of Advisors on Science and Technology, *Engage to Excel.*

institutions to integrate the development of these skills across the curriculum, including communications, collaboration, problem definition and design, and entrepreneurial skills.

Recommendation 4.4. Support efforts to achieve vertical integration

There is a need to increase the coherence of students' learning experiences across the curriculum and facilitate an understanding of how to promote the transfer of knowledge across disciplines. Funders should support institutions in establishing cross-disciplinary courses during the first two years that introduce the languages of each of the disciplines and help students understand disciplinary perspectives and interrelated problems.

Recommendation 4.5. Continue to explore and fund novel approaches to the first two years of STEM coursework

Given the rapid pace of change, it will continue to be appropriate to explore novel approaches to STEM coursework.

RECOMMENDED RESOURCES

Brown, M. K., C. J. Finelli, and C. O. Neal. 2009. *Teaching for Retention in Science, Engineering, and Math Disciplines: A Guide for Faculty.* Ann Arbor: University of Michigan Center for Research on Teaching and Learning. Retrieved from http://www.crlt.umich.edu/sites/default/files/resource_files/CRLT_no25.pdf

Gasiewski, J. A., M. K. Eagan, G. A. Garcia, S. Hurtado, and M. J. Chang. 2012. "From Gatekeeping to Engagement: A Multicontextual, Mixed Method Study of Student Academic Engagement in Introductory STEM Courses." *Research in Higher Education* 53 (2): 229–261.

Kuh, G. D. 2008. *High-Impact Educational Practices: What They Are, Who Has Access to Them, and Why They Matter.* Washington, DC: Association of American Colleges and Universities.

RELATED PROJECTS AND PROGRAMS

SENCER

Science Education for New Civic Engagements and Responsibilities (SENCER) connects STEM content to complex local, national, and global challenges of civic consequence. Civic engagement builds community, is attractive to diverse students, helps build twenty-first-century skills, and provides opportunities to embed attention to ethical responsibility into the planning of the curriculum. SENCER aims to make STEM more engaging while strengthening students' understanding of STEM and their capacity to apply their knowledge to real-world issues. By teaching STEM content through the context of complex issues, this approach encourages students to think across disciplines and to understand the process, nature, and limits of science.
See http://www.sencer.net/.

VIP Program

Georgia Tech's Vertically Integrated Projects (VIP) program engages students in long-term research and development projects in order to foster innovative thinking and entrepreneurial skills. Students work in large, multidisciplinary teams on challenging, real-world projects that are of significance to faculty members' research programs. Projects are vertically integrated in that they maintain a mix of sophomores through PhD students each semester. Students are encouraged to participate for up to three years, and new students are added to projects as original team members graduate. Core components of the VIP program include mentoring, cooperative learning, and development of professional skills.
See http://vip.gatech.edu/.

Integrated Quantitative Science

At the University of Richmond, prospective STEM majors can enroll in an integrated quantitative science (IQS) course that incorporates first-semester content in biology, chemistry, physics, mathematics, and computer science in one fully integrated experience during the first year. Each semester of IQS is organized around a societally relevant theme with a focus on inquiry-based pedagogy and interdisciplinary thinking. To encourage them to think like scientists, students engage in experiments, simulations, and modeling that draw from the principles of the core STEM disciplines. Students who participate in the IQS course receive stipend support to conduct research with a faculty mentor during the following summer.
See http://iqscience.richmond.edu/.

TRACKING IMPROVEMENT
IN STEM EDUCATION

In order to transform STEM education, and to ensure that initiatives are making progress, we need robust ways to determine whether there is alignment between what we know about how students learn and what they experience. The quality of evidence presented to support claims of the success or failure of a given educational intervention is often inconsistent. In a recent literature review of articles on curricular approaches in STEM education, only 21 percent presented strong evidence, while 28 percent offered adequate evidence, 39 percent poor evidence, and 12 percent no evidence.[37]

Studies that rely on self-reported data are also problematic, as in a recent faculty survey showing that a clear majority thought of themselves as above-average teachers.[38] Self-reported usage of particular evidence-based practices tends to yield inconsistencies in estimates of the uptake of a given approach. Faculty may report using evidence-based approaches while further investigation shows that actual classroom practice is often inconsistent with that strategy.[39]

Understanding fidelity of implementation is key to the evaluation process. Without this information, it is not possible to determine whether innovations are unsuccessful because of improper implementation, an incorrect model of change, or situational factors.

We ***NEED ROBUST WAYS*** to determine ***WHETHER THERE IS ALIGNMENT*** between ***WHAT WE KNOW*** about how students learn and ***WHAT THEY EXPERIENCE.***

Faculty tend to adapt evidence-based practices to their own circumstances, but these modifications are often in the direction of making the practice more traditional.[39] In some cases, faculty may not have an adequate understanding of a given innovation to maintain the underlying model of change.

Taken together, these findings indicate that a shift is needed away from presenting evidence of effective practices to the practical details of successful adoption and adaptation. It is therefore crucial that innovations are tested and refined in environments fundamentally different from where they were developed, and that developers are explicit about what aspects will transfer and under what conditions the transfer will be successful, as well as offering recommendations for modifications suitable for different contexts.[37]

[37] Henderson and Dancy, *Increasing the Impact and Diffusion of STEM Education Innovations.*

[38] Vikram Savkar and Jillian Lokere, *Time to Decide: The Ambivalence of the World of Science toward Education* (Cambridge, MA: Nature Publishing Group, 2010), 1–15.

[39] Dancy and Henderson, "Pedagogical Practices and Instructional Change of Physics Faculty."

Developing and implementing effective instruments for evaluating teaching is a crucial step in scaling up and sustaining improvements. Faculty overwhelmingly believe that typical student evaluations are not an effective means of measuring teaching quality and that a standardized and robust set of metrics are required to fully understand how particular practices affect student outcomes.[40]

Assessment and evaluation efforts are complicated by the absence of robust and accessible data systems within most colleges and universities. The existence and availability of these data are necessary to not only effectively track the impacts of initiatives, but also to continually improve teaching and learning at the institutional and course levels. These systems must be designed with the unique needs of multiple stakeholder groups in mind, and the translation of data into actionable knowledge for administrators and faculty should be a top priority.

Goal 5. Expect institutions to address systemic change through measurable indicators and evaluation

Effective designs for tracking improvement in STEM education require the articulation of specific indicators (metrics). Data can be collected using a variety of methods including surveys, observations, interviews, and focus groups. These instruments can be administered at various times including before, during, and after a course. In particular, exit interviews with graduating students can shed light on the important factors that influence student persistence and learning outcomes. Adequate resources and time for assessment must be prioritized.

The ultimate goal of any teaching activity is student learning and engagement. This is the case for instruction in any course as well as funded interventions designed specifically to improve learning outcomes, retention in STEM, or an increase in the number of STEM degrees. It is important to remember that teaching and learning exist within complex institutional environments. Institutions should develop an overarching framework for data collection that establishes accountability and articulates objectives and appropriate indicators. Data should be used to inform decision making at all levels.

No matter what activity a funder supports, the following are institutional actions to look for when assessing whether systemic change is being addressed:

Recommendation 5.1. Institutions should propose measurable objectives and develop plans for annual review and evaluation along key indicators

During this process, institutions might consider

- the reasonableness of what can be measured in a given time frame;
- the cost per student; and
- what is scalable within resource constraints.

Recommendation 5.2. Require faculty to establish assessment of effectiveness

Faculty should be required to establish assessment of effectiveness of teaching as they design and implement new curricula. Ideally, they would identify student learning goals, collect data on the extent to which those goals are being met, and then feed data back into improvement efforts.

Recommendation 5.3. Institutions should distribute data on student success, establish benchmarks to be measured across programs, and hold departments accountable for performance

Institutions routinely collect data on student success (e.g., persistence and graduation rates and results from national surveys such as the National Survey of Student Engagement). There should be better linkages between institutional data and departmental performance and accountability, with rewards for departments that meet metrics of success. Institutions should consider developing an institutional dashboard of student learning and success indicators that is broadly accessible both within the institution and outside of it. Departments should be encouraged to use these data in local improvement efforts.

Recommendation 5.4. Institutions should track effective use of resources for faculty support of educational improvements

To help incentivize and sustain reforms, institutions should develop and track metrics that show how resources are saved when reforms have positive impacts on student learning and success.

[40] Savkar and Lokere, *Time to Decide.*

RECOMMENDED RESOURCES

American Association for the Advancement of Science. 2013. *Describing & Measuring Undergraduate STEM Teaching Practices.* Washington, DC.: American Association for the Advancement of Science.

Smith, M. K., F. H. M. Jones, S. L. Gilbert, and C. E. Wieman. 2013. "The Classroom Observation Protocol for Undergraduate STEM (COPUS): A New Instrument to Characterize University STEM Classroom Practices." *CBE–Life Sciences Education* 12, 618–627.

Aguirre, K. M., et al. 2013. "PULSE Vision & Change Rubrics." *CBE–Life Sciences Education*, 12 (4): 579–581.

RELATED PROJECTS AND PROGRAMS

California State University Data Systems

The California State University (CSU) system, the largest public university system in the United States, has standardized its financial, human resources, student administration, and alumni development systems across all twenty-three of its campuses and the Office of the Chancellor. Using Oracle's PeopleSoft platform, the move toward a common system is part of CSU's strategic plan to take advantage of technology to meet the future educational needs of students, faculty, and staff. The availability of robust, comparable data across campuses makes actionable knowledge more readily available to administrators, faculty, and other stakeholders.

COPUS

In order to determine whether there is alignment between what students experience and what we know about how they learn, institutions must be able to determine the extent to which evidence-based pedagogies are being implemented in classrooms. The Classroom Observation Protocol for Undergraduate STEM (COPUS) was developed to collect information about the nature of STEM teaching practices. A critical design feature of the COPUS is that faculty who have little or no observation protocol experience and minimal time for training can use it reliably. The protocol is easy to learn, requiring only 1.5 hours of training, and characterizes nonjudgmentally what instructors and students are doing during a class. COPUS provides data that can be useful for a wide range of applications, from improving an individual's teaching of a course to comparing practices longitudinally or across courses, departments, and institutions.

PULSE Vision & Change Rubrics

The PULSE (Partnership for Undergraduate Life Sciences Education) Vision & Change Rubrics characterize a set of metrics for evaluating the degree of departmental adoption of evidence-based practices in the life sciences. These rubrics assess department or program alignment with recommendations made by the Vision and Change in Undergraduate Biology Education initiative in five broad areas: curriculum alignment, assessment, faculty practice/faculty support, infrastructure, and climate for change. The descriptors under each area designate levels of implementation from first steps to full departmental transformation. The rubrics have been designed to be flexible and inclusive, such that they can be used at a broad range of institutional types including two-year colleges, four-year liberal arts institutions, regional comprehensive institutions, and research institutions. Ultimately, the rubrics are intended to serve as the basis for a tiered certification program for life science departments that have adopted some or all of the Vision & Change recommendations, and to encourage self-reflection and strategic planning for those who have not yet done so.
See www.pulsecommunity.org.

SUSTAINING CHANGE

While grant funding for STEM education projects is typically three to five years in duration, impacts of funding may not be felt for five to ten years. Funding levels must be sufficient to firmly catalyze change, and must require a plan for sustaining the work after the funding period. Requiring matching funds from institutions is a key tool for ensuring institutional buy-in at the president/provost level. Institutions must also have plans for sustaining the changes after the funding period, and these plans must be built in to the project from its inception. Sufficient support should be provided for continued evaluation after the intervention. To achieve sustained change, institutions must develop financial, infrastructural, and leadership models that support the cultural changes they plan to effect. Funded projects can only be catalysts for broader action.

Goal 6. Expect institutions to plan for sustained change

Regardless of the project being pursued, funders should expect institutions to address and plan for sustainable long-term change.

Recommendation 6.1. Institutions should plan for the long-term sustainability of programs and projects

In order to break the cycle of isolated course or program reforms, institutions should consider the characteristics of:

Structures: What norms, infrastructures, and policies should be prioritized or modified to sustain the program (e.g., faculty workload, balance of disciplinary and interdisciplinary courses, employer connections, community connections, and funding)? Which ones are most likely to help sustain the effort within the university?

Vision: How can excellence in STEM education become a central component of the campus vision? Is it articulated in campus strategic goals? Are resources aligned to support it?

Students: What student outcomes are especially important for courses and programs over the long term? What are the foundational "big ideas" and emerging trends in the field? What post-graduate opportunities is the program preparing students for and what outcomes do students need to be successful? How are these outcomes connected to program structure and learning experiences?

Personnel: Do faculty have the expertise, time, resources, and other support needed to plan and implement changes? What faculty development programs does the campus have to foster innovation in undergraduate programs? What investments are being made in developing the faculty and providing them with needed supports?

Institutions should consider the development or use of an institutional readiness, asset-mapping tool to help consider these questions.

Recommendation 6.2. Create linkages between institutional data and departmental performance and accountability

Regular program reviews or annual departmental reports should contain sections that require addressing key program and institutional data with respect to benchmarks and targets. These documents should require departments to address strategies they are using to positively impact student learning and success at the program level. Funding and hiring incentives can be attached to positive progress on these metrics. A department or program's strategic use of data should be linked to institutional incentives and priorities.

Recommendation 6.3. Participate in continuous improvement networks

Complex improvement efforts require sustained and collective action in order to achieve long-term success. One model for a mechanism that supports such efforts is that of the networked improvement community. A networked improvement community enables individuals to contribute diverse expertise to a common problem, and is particularly well-suited to encourage information exchange and innovation.[41]

RECOMMENDED RESOURCES

Austin, A. 2011. "Promoting Evidence-Based Change in Undergraduate Science Education: A Paper Commissioned by the National Academies National Research Council Board on Science Education." Retrieved from http://sites.nationalacademies.org/DBASSE/BOSE/DBASSE_071087.

Bryk, A. S., L. M. Gomez, and A. Grunow. 2011. "Getting Ideas into Action: Building Networked Improvement Communities in Education." In *Frontiers in Sociology of Education*, edited by M. Hallinan. New York: Springer Publishing. http://www.carnegiefoundation.org/sites/default/files/bryk-gomez_building-nics-education.pdf.

Kezar, A. 2011. "What Is the Best Way to Achieve Broader Reach of Improved Practices in Higher Education?" *Innovative Higher Education* 36 (4): 235–247.

Kezar, A., and S. Elrod. 2012. "Facilitating Interdisciplinary Learning: Lessons from Project Kaleidoscope." *Change* 44 (1): 13–21.

[41] Anthony S. Bryk, Louis M. Gomez, and Alicia Grunow, "Getting Ideas into Action: Building Networked Improvement Communities in Education," in *Frontiers in Sociology of Education*, ed. Maureen Hallinan (New York: Springer Publishing, 2011), http://www.carnegiefoundation.org/sites/default/files/bryk-gomez_building-nics-education.pdf.

RELATED PROJECTS AND PROGRAMS

Bay View Alliance

Following the networked improvement community model, the Bay View Alliance (BVA) is a consortium of research universities carrying out applied research on the leadership of cultural change for increasing the adoption of evidence-based teaching practices. The BVA does not focus directly on teaching methods; instead, members address issues related to leadership, motivation, organizational culture, and change management that support and sustain improved teaching practices. Members of the consortium work together to identify and evaluate more effective ways for university leaders at all levels to inspire and enable improved teaching and learning.
See http://bayviewalliance.org/.

Keck/PKAL STEM Education Effectiveness Framework Project

The Keck/PKAL STEM Education Effectiveness Framework project is working to develop a comprehensive framework that will help campus leaders translate national recommendations for improving teaching and learning in STEM into scalable and sustainable actions. Participating campuses in California are contributing to the development of an institutional readiness audit and a rubric with benchmarking tools that colleges and universities can use to measure their effectiveness in promoting more learner-centered campus cultures in STEM. These tools are intended to guide campuses through program, departmental, and, eventually, institutional transformation. The project pays specific attention to program and institutional data that can be used to evaluate student achievement, experiences, and progress (e.g., rates of transfer, retention, and completion) with a focus on minority student success.
See http://www.aacu.org/pkal/educationframework.

Association of American Universities: Undergraduate STEM Education Initiative

The AAU Undergraduate STEM Education Initiative seeks to achieve systemic and sustained improvements in STEM learning at its member institutions, which consist of leading public and private research universities. The goals of the initiative include helping institutions assess the quality of STEM teaching on their campuses, share best practices, and create incentives for their departments and faculty members to adopt effective teaching methods. The initiative has developed a framework for systemic change designed to help institutions assess and improve the quality of STEM teaching and learning, particularly during the first two years of college. A demonstration program at a subset of AAU universities is implementing the framework and exploring mechanisms that institutions and departments can use to train, recognize, and reward faculty members who want to improve the quality of their STEM teaching.
See www.aau.edu/STEM.

ADDRESSING THE SYSTEMIC NATURE OF CHANGE:
ADDITIONAL LEVERAGE POINTS WITHIN UNDERGRADUATE INSTITUTIONS

Higher education serves a crucial role in preparing K–12 STEM teachers and providing them with the tools to develop the next generation of US STEM talent. Great strides have been made in understanding effective K–12 STEM teaching and providing evidence-based guidance for K–12 learning. For example, the *Next Generation Science Standards* provide a comprehensive, coherent framework for K–12 competencies by grade level and core discipline. A movement toward competency-based standards is placing more emphasis on what students should be able to do with their knowledge, including critical thinking and analysis (see http://www.nextgenscience.org/next-generation-science-standards).

In spite of this progress, the Trends in International Mathematics and Science Study reports that performance gaps in STEM persist for US students compared to other developed countries, which has serious repercussions for higher education (see http://timssandpirls.bc.edu/). Equally troubling is that these gaps appear early, and that minority and low-income students continue to lag behind their peers in both math and science. Student interest in STEM is also a key factor, as STEM-capable students are diverting away from STEM fields before college.[42] This pattern illustrates that competency is necessary but not sufficient for improving the nation's STEM outlook.

Early experiences in math and science clearly affect students' intent to major in STEM fields.[43] Teacher preparation shapes these experiences and affects both student interest and performance in STEM. While middle or high school STEM teachers may have been STEM majors, teachers at the K–5 level typically learn college-level math and science in general education courses. Among K–5 teachers, 71 percent of those surveyed indicate they feel they are only somewhat, a little, or not at all science literate.[44] When asked to grade their own pre-service preparation to teach core subjects, 42 percent assigned a C or below to their preparation in science, and 66 percent assigned a C or below to their preparation in math.

More than one-third of new K–5 teachers indicate that when teaching their students science, they rely more on what they learned from their high school science courses than from their pre-service preparation in college.[44] Middle and high school teachers fare somewhat better, but few

[42] Carnevale, Smith, and Melton, *STEM.*

[43] Xueli Wang, "Why Students Choose STEM Majors: Motivation, High School Learning, and Postsecondary Context of Support," *American Educational Research Journal* 50 (2013): 1081–1121.

[44] Market Research Institute Inc., *The Bayer Facts of Science Education X: Are the Nation's Colleges and Universities Adequately Preparing Elementary Schoolteachers of Tomorrow to Teach Science?* (Shawnee Mission, KS: Bayer Corporation, 2004), http://www.bayerus.com/msms/web_docs/040511_Exec_Summary.pdf.

teacher preparation programs put a strong emphasis on both STEM content mastery and pedagogical training.[45] Improving teacher preparation programs is a strong point of leverage both for developing STEM talent and for ensuring a STEM-literate citizenry.

Goal 7. Strengthen teacher preparation programs

Recommendation 7.1. Invest in scaling up successful teacher preparation programs

Scale up evidence-based programs that have resulted in creating effective teachers (e.g., UTeach and SMTI in the Related Projects and Programs box below).

Recommendation 7.2. Improve recruitment of students into STEM teaching, especially for underrepresented groups

Encouraging more undergraduate students to pursue K–12 teaching in STEM is vital to improving STEM learning, especially for students who are traditionally underrepresented in the STEM disciplines.

RECOMMENDED RESOURCE

President's Council of Advisors on Science and Technology. 2010. *Prepare and Inspire: K–12 Education in Science, Technology, Engineering, and Math (STEM) for America's Future*. Washington, DC.

RELATED PROJECTS AND PROGRAMS

SMTI

The Association of Public and Land-grant Universities' Science & Mathematics Teacher Imperative (SMTI) works with public universities to increase the number and improve the quality and diversity of the science and mathematics teachers they prepare. SMTI has developed an "Analytic Framework" that allows faculty and administrators to analyze policies, processes, and practices that support effective preparation of science and mathematics teachers. An understanding of the factors required for sustained institutional change, including top leadership commitment and faculty ownership, is key to SMTI efforts on campuses. See http://www.aplu.org/page.aspx?pid=2776.

UTeach

First developed at the University of Texas at Austin, the UTeach model is now coordinated through the UTeach Institute and is used by forty institutions across the country. UTeach was created to attract science and mathematics majors to secondary teaching careers, to prepare them through an advanced field-intensive curriculum, and to promote retention through ongoing professional development. The program is a formally coordinated effort of the equivalents of the College of Education, the College of Liberal Arts, and the college(s) responsible for administering STEM degrees. UTeach works to actively recruit STEM majors and maximize retention within the program. Students work with master teachers to develop strong understanding of both STEM content and connections between educational theory and practice. See http://uteach-institute.org/.

Bush Foundation: Network for Excellence in Teaching

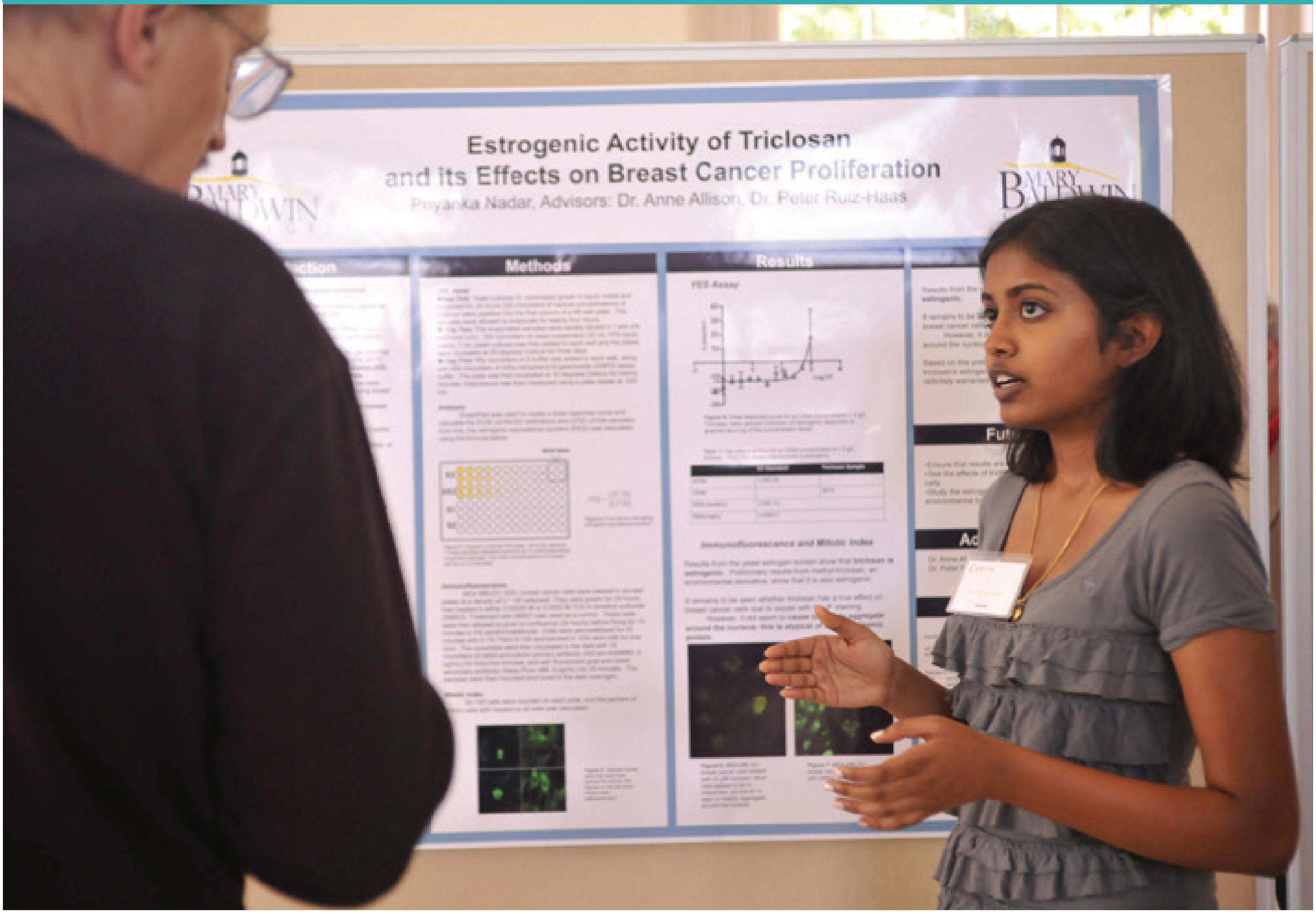
The Bush Foundation's Network for Excellence in Teaching (NExT) works to recruit, train, and support science and math teachers in Minnesota, South Dakota, North Dakota, and twenty-three Native nations. The initiative has partnerships with fourteen higher education institutions within the region and works to actively recruit and prepare students who will pursue teaching careers in high-demand subject areas, including STEM disciplines. Central goals of the initiative include increasing the diversity of teachers and working to close achievement gaps for traditionally underrepresented groups. See http://nextteacher.org/.

[45] Jeremy Kilpatrick and Helen Quinn, *Science and Mathematics Education* (Washington, DC: National Academy of Education, 2009).

COMMUNICATION OF STEM

Workshop participants emphasized the need for improved communication among scientists, policy makers, and the public. The typical "transmission of information" model, which mirrors and may well be rooted in lecture-based instructional practices, has not yielded improvements in scientific literacy or the level of discourse around complex, contested issues. Issues that lie at the intersection of science and politics, such as climate change and evolution, are not only informed by scientific information, but are also framed by value predispositions such as moral, political, and religious beliefs (Nisbet and Mooney 2007). The presumption of ignorance about key issues, or the "deficit" model, does not take into account these values and the diversity of perspectives held by the public. A common assumption is that once the facts are presented and understood, public opinion will align with the scientific enterprise and controversies will subside. Instead, communications experts recommend empirical approaches to communication about STEM that take into account how the public makes sense of scientific information and the contextual frames that influence them. These approaches include improving public dialogue about scientific issues, placing greater emphasis on understanding personal value systems, and integration of communications coursework in STEM undergraduate and graduate programs (Nisbet and Scheufele 2009).

Sources: Matthew C. Nisbet and Chris Mooney. 2007. "Policy Forum: Framing Science." *Science* 316 (5821): 56; Matthew C. Nisbet and Dietram A. Scheufele. 2009. "What's Next for Science Communication? Promising Directions and Lingering Distractions." *American Journal of Botany* 96 (10): 1767–1778.



LEVERAGE POINTS
OUTSIDE UNDERGRADUATE INSTITUTIONS

Achieving sustained improvement in undergraduate STEM education will require actions both internal and external to undergraduate institutions. Workshop participants identified the following leverage points that offer additional opportunities to address systemic change.

Articulations between Two- and Four-Year Institutions

Increasing numbers of STEM students begin their studies in community colleges, and better articulations are needed between two- and four-year institutions. A recent summit held by the National Academy of Sciences highlighted the role of community colleges in broadening the participation of underrepresented groups in STEM and emphasized the need for articulation agreements, summer bridge programs, mentoring, and peer tutoring, among other practices.[46]

Accreditation

The changing landscape of institutions has significant implications for accrediting agencies. Currently, there is no clear alignment between accreditation standards and evidence-based teaching practices. Accreditors can also hold institutions accountable for unsupportive practices. A shift away from state governments and toward accreditors as the primary external force acting on institutions means that such agencies are positioned to have a significant impact on accountability.[47] Accrediting agencies should set expectations that institutions will measure explicit learning outcomes.

Disciplinary Societies

A faculty member's academic discipline is typically the greatest influence shaping his or her professional behaviors and attitudes.[48] Departmental norms often reinforce these behaviors. As such, department-level initiatives and departmental leadership can have a significant impact on the type of teaching that occurs within the department.[49] The role of disciplinary identity also reinforces the influence that professional disciplinary societies can have in establishing norms about what it means to be a professional within that discipline. These organizations are a potential leverage point to provide increased visibility and importance to teaching as an integral part of one's professional identity.

Disciplinary societies could offer certifications, both for faculty practice and for departmental policy and

[46] National Research Council, *Community Colleges in the Evolving STEM Education Landscape: Summary of a Summit*, (Washington, DC: The National Academies Press, 2012).

[47] Peter T. Ewell, *Assessment, Accountability, and Improvement: Revisiting the Tension* (Champaign, IL: National Institute for Learning Outcomes Assessment, 2009), http://www.learningoutcomeassessment.org/documents/PeterEwell_005.pdf.

[48] John C. Smart, Kenneth A. Feldman, and Corrina A. Ethington, *Academic Disciplines: Holland's Theory and the Study of College Students and Faculty* (Nashville, TN: Vanderbilt University Press, 2000).

[49] Paul Ramsden, et al., "University Teachers' Experiences of Academic Leadership and Their Approaches to Teaching," *Learning and Instruction* 17 (2007): 140–155.

practice, as evidence of alignment with disciplinary norms for excellence in instruction. Funders could support disciplinary societies in developing a certification process focused on effective teaching practice and including common standards and a "seal of approval." Accrediting agencies could then use these standards to establish criteria for accreditation. A two-year pilot group could be established by an initial cohort of societies. Certification may exist in two forms: an initial certification for graduate students, post-docs, or faculty members within the first two years of their appointment, and a "mid-career" version for established faculty to refresh their skills. This would apply to tenure-track, non-tenure-track, adjunct, and all other forms of appointment.

Articulations with Industry and Employers

Industry and employers have opportunities to inform course content and career pathways through internships, research opportunities, and other valuable real-world connections and experiences. Partnerships between education and industry help establish workforce expectations and definitions of employability. Cross-collaboration between industry associations and accrediting entities can help ensure that students are well-prepared with soft skills that include communication, critical thinking, problem solving, and teamwork. Higher education should be connected with the labor market in an adaptable manner that recognizes the need for flexibility and an awareness that we don't know future workforce needs with absolute certainty. For example, the Business–Higher Education Forum (BHEF) promotes collaboration between business and higher education to increase baccalaureate attainment (especially for underrepresented groups), better align higher education with workforce needs, and ensure the achievement of essential learning outcomes (for more information, see http://www.bhef.com/).

Additional Resources

The white papers commissioned for this workshop can be found at www.aacu.org/CRUSE

Ann Austin: Barriers to change in higher education: Taking a systems approach to transforming undergraduate STEM education

William Bonvillian: What does the "MOOC Tsunami" mean for reforming undergraduate education?

Shirley Malcom: Guess who's coming to college: Shifting demographics and what they mean for higher education

Susan Singer: Discipline-based education research: Understanding and improving learning in undergraduate science and engineering

Martin Storksdieck: Summary of engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics

Michael Tanner: Effective use of technology

Michael Teitelbaum: STEM retention and drawing in underrepresented groups

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ABOUT THE COALITION FOR REFORM OF UNDERGRADUATE STEM EDUCATION

We share the belief that the culture of undergraduate STEM education must shift from reliance on lecturing to activities inside and outside the classroom that engage students directly, and that draw in a student body that is fully representative of the diversity of our population. Our common experience is that initiatives that support change at the individual faculty, course, or curriculum level have not been enough to bring about this cultural shift. We also believe that forces are now aligned that could cause a cultural shift to evidence-based practice.

The Coalition is grateful for the enthusiastic support and advice of the leadership of its member organizations, and the generous contributions of time and expertise by participating staff. We thank the Alfred P. Sloan Foundation for support of our ongoing activities.

As of the 2013 workshop, Coalition members included staff from the American Association for the Advancement of Science, the Association of American Colleges and Universities, the Association of American Universities, and the Association of Public and Land-grant Universities. The Coalition is convened by Dr. Linda Slakey (Senior Adviser, AAU and Senior Fellow, AAC&U).

American Association for the Advancement of Science (www.aaas.org)

AAAS

The American Association for the Advancement of Science (AAAS) is the world's largest general scientific society and publisher of the journal *Science* as well as *Science Translational Medicine* and *Science Signaling*. AAAS was founded in 1848 and includes some 261 affiliated societies and academies of science, serving 10 million individuals. *Science* has the largest paid circulation of any peer-reviewed general science journal in the world, with an estimated total readership of 1 million. The nonprofit AAAS is open to all and fulfills its mission to "advance science and serve society" through initiatives in science policy, international programs, science education, public engagement, and more. For the latest research news, log onto EurekAlert!, the premier science-news website, a service of AAAS.

Association of American Colleges and Universities (www.aacu.org)

AAC&U *Association of American Colleges and Universities*

The Association of American Colleges and Universities (AAC&U) is the leading national association concerned with the quality, vitality, and public standing of undergraduate liberal education. Founded in 1915, AAC&U now comprises more than 1,300 member institutions—including accredited public and private colleges, community colleges, research universities, and comprehensive universities of every type and size. Through its publications, meetings, public advocacy, and programs, AAC&U works to reinforce the commitment to liberal education at both the national and the local level and to help individual colleges and universities keep the quality of student learning at the core of their work as they evolve to meet new economic and social challenges.

Association of American Universities (www.aau.edu)

The Association of American Universities (AAU) is a nonprofit organization of sixty-two leading public and private research universities in the United States and Canada. Founded in 1900 to advance the international standing of US research universities, AAU today focuses on issues that are important to research-intensive universities, such as funding for research, research policy issues, and graduate and undergraduate education. AAU programs and projects address institutional issues facing its member universities, as well as government actions that affect these and other universities. The major activities of the association include federal government relations, policy studies, and public affairs.

Association of Public and Land-grant Universities (www.aplu.org)

The Association of Public and Land-grant Universities (APLU) is a research, policy, and advocacy organization representing 235 public research universities, land-grant institutions, state university systems, and affiliated organizations. Founded in 1887, APLU is North America's oldest higher education association, with member institutions in all fifty US states, the District of Columbia, four US territories, Canada, and Mexico. APLU's membership includes 204 campuses and twenty-five university systems, including seventy-five US land-grant institutions. APLU is dedicated to advancing learning, discovery, and engagement. The association provides a forum for the discussion and development of policies and programs affecting higher education and the public interest.

ABOUT THE EDITOR

Catherine L. Fry edited this publication while serving as a project manager for Project Kaleidoscope at the Association of American Colleges and Universities (AAC&U) in Washington, DC. Prior to joining AAC&U, she worked at the National Science Foundation's Division of Undergraduate Education through a competitive Science & Technology Policy Fellowship from the American Association for the Advancement of Science. She is currently the Education Manager for the American Society for Pharmacology & Experimental Therapeutics. Catherine earned her PhD in ecology and evolutionary biology in 2006 from the University of Maryland at College Park. She also holds a BA in biology and environmental science from Knox College.