PROGRESS TOWARD ACHIEVING SYSTEMIC CHANGE:

A Five-Year Status Report on the AAU Undergraduate STEM Education Initiative

Association of American Universities
Inquiry · Innovation · Impact

Suggested citation: Association of American Universities. (2017). *Progress Toward Achieving Systemic Change: A Five-Year Status Report on the AAU Undergraduate STEM Education Initiative.* Washington, DC.

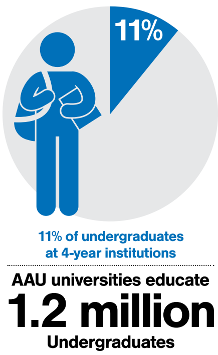
Acknowledgements

Several key activities of the AAU Undergraduate STEM Education Initiative are made possible by funds from The Leona M. and Harry B. Helmsley Charitable Trust, the National Science Foundation, Northrop Grumman Foundation, the Burroughs Wellcome Fund, Elsevier, and Research Corporation for Science Advancement. The resulting analysis and recommendations presented in this report do not necessarily represent the views of the funders.

Many collaborators and staff members played key roles in the development and implementation of the Undergraduate STEM Education Initiative as well as in the creation of this report: Lillian Aoki, former AAU Policy and STEM Intern; Robert Berdahl, AAU President emeritus; Emiko Blalock, former graduate student at Michigan State University; Mary Sue Coleman, AAU President; James Fairweather, AAU Co-Principal Investigator; Mackenzie "Mac" Hird, former AAU Policy Intern; Kristen Hodge-Clark, former AAAS Fellow; Tara King, AAU Higher Education Project Coordinator; Jodi Linley, former graduate student at Michigan State University; Emily Miller, AAU Associate Vice President for Policy; Hannah Poulson, AAU Policy Associate; Karen Paulson, formerly at the National Center for Higher Education Management Systems; Linda Slakey, AAU Senior Policy Advisor; Tobin Smith, AAU Vice President for Policy; Matt Stephen, former AAU Policy Assistant; and Josh Trapani, former AAU Associate Vice President for Research and Policy Analysis. We also are grateful for the guidance provided by the Advisory Committee to help advance the Initiative.

We would also like to draw special attention to the role played by former AAU President, Hunter R. Rawlings III, in launching and serving as the driving force behind the AAU Undergraduate STEM Education Initiative. His commitment to improving the quality of undergraduate education at AAU institutions played a significant factor in the success of the Initiative.

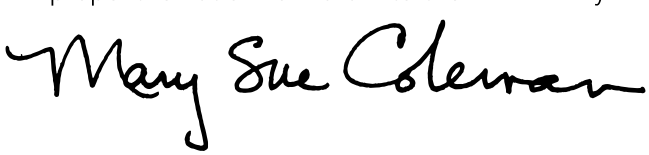
A Message from the President



AAU institutions are distinguished for their world-class research and the quality of their graduate education programs. Less recognized and valued is the role AAU universities play in undergraduate education. Yet AAU institutions educate close to 1.2 million undergraduate students every academic year. In educating these undergraduate students, AAU universities have a responsibility to promote the use of evidence-based teaching practices proven by research to be most effective at advancing student success. Additionally, they must provide their faculty members with the encouragement, training, and support to effectively employ these instructional approaches in the classroom. The AAU Undergraduate STEM Education Initiative is a significant test of the degree to which a group of prominent research universities can work collectively with their national organization to improve the quality of teaching in undergraduate STEM courses, especially large introductory and gateway courses, thereby enhancing the learning experiences of many thousands of their undergraduate students.

The results of the Initiative thus far indicate a resoundingly affirmative answer to this test. At the same time, the Initiative has helped AAU understand how it, as a major association of research universities, can help to support meaningful change at various institutional levels to improve undergraduate STEM education. While there is much work to be done to realize a 'new normal' – one characterized by personal and institutional expectations that all faculty members will both use and be rewarded for using evidence-based approaches to instruction – our Initiative suggests that progress is being made.

AAU continues its commitment to achieving widespread systemic change in this area and to promoting excellence in undergraduate education at major research universities. We are now reaching a major tipping point. We cannot condone poor teaching of introductory STEM courses because we are trying to weed out the weaker students in the class or simply because a professor, department and/or institution fails to recognize and accept that there are, in fact, more effective ways to teach. Failing to implement evidence-based teaching practices in the classroom must be viewed as irresponsible, an abrogation of fulfilling our collective mission to ensure that all students who are interested in learning and enrolled in a STEM course – not just those who will choose to major in or pursue an advanced degree in that discipline – are provided with the maximum opportunity to succeed. This change is what is needed to ensure that we have the STEM-literate workforce and general population required to propel the nation forward into the 21st century and beyond.



Mary Sue Coleman
President
Association of American Universities

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Objective

To influence the culture of STEM departments at AAU institutions so that faculty members are encouraged and supported to use teaching practices proven by research to be effective in engaging students in STEM education and in helping students learn.

Goals

1. Develop an effective analytical framework for assessing and improving the quality of STEM teaching and learning, particularly in the first two years of college.

2. Support AAU STEM project sites at a subset of AAU universities to implement the Framework, and develop a broader network of AAU universities committed to implementing STEM teaching and learning reforms.

3. Explore means that institutions and departments can use to train, recognize, and reward faculty members who want to improve the quality and effectiveness of their STEM teaching.

4. Work with federal research agencies to develop means of recognizing, rewarding and promoting efforts to improve undergraduate learning.

5. Develop effective means for sharing information about promising and effective undergraduate STEM education programs, approaches, methods, and pedagogies.

Executive Summary

In September 2011, the Association of American Universities launched a major initiative to improve undergraduate STEM education. The overall objective was to influence the culture of STEM departments at AAU institutions so that faculty members are encouraged and supported to use teaching practices proven by research to be effective in engaging students in STEM education and in helping students learn.

The Undergraduate STEM Education Initiative's intent was to help research universities better assess and improve the quality of teaching in STEM fields by: promoting the use of teaching techniques in STEM classes demonstrated by scholarship to be the most effective at engaging and helping students learn; encouraging universities and STEM departments to better evaluate, recognize and reward faculty members for the quality and effectiveness of their teaching; and facilitate the creation of an effective network for disseminating and sharing best practices in undergraduate STEM education reform and classroom based educational improvements.

AAU's Initiative was not launched with the intention of producing yet another report. Instead, its aim was to encourage and support research universities to act upon and implement recommendations already made in national reports.[1, 2] The initiative was, in some sense, an experiment to see if as a leading association of research universities, AAU could facilitate meaningful and long-lasting systemic change in undergraduate STEM education by providing its members with a framework accompanied by additional tools, support, and encouragement.

To help with this effort, AAU established a project team and convened an advisory committee composed of experts in undergraduate STEM teaching and learning. It also established five overarching goals for the initiative:

1. Develop an effective analytical framework for assessing and improving the quality of STEM teaching and learning, particularly in the first two years of college.

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).

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

2. Support AAU STEM project sites at a subset of AAU universities to implement the Framework, and develop a broader network of AAU universities committed to implementing STEM teaching and learning reforms.
3. Explore means that institutions and departments can use to train, recognize, and reward faculty members who want to improve the quality and effectiveness of their STEM teaching.
4. Work with federal research agencies to develop means of recognizing, rewarding and promoting efforts to improve undergraduate learning.
5. Develop effective means for sharing information about promising and effective undergraduate STEM education programs, approaches, methods, and pedagogies.

Since the Initiative was launched, AAU has received 11 grants ($7.9M) from private and corporate foundations and the federal government to advance the Initiative. *Progress Toward Achieving Systemic Change* provides a five-year status report on the AAU Undergraduate STEM Education Initiative.

Engagement by AAU Universities

AAU universities have demonstrated widespread enthusiasm and interest in the Initiative.

Participation in the Initiative by AAU member institutions has been high. This is demonstrated by the fact that all 62 AAU institutions have designated a STEM Campus Point of Contact to serve as a liaison between AAU and his or her campus for the Initiative.

- To date, 55 AAU member universities have participated in the Initiative, including more than 450 unique faculty members and institutional leaders.
- 42 institutions convened campus stakeholders (e.g., faculty members and administrators) to respond to our request for comments on the initial Framework draft.
- Over half of AAU's membership is active in the AAU STEM Network and more than 275 unique faculty members and institutional leaders have participated in network events.
- 31 institutions submitted proposals to be considered as a STEM Project Site and to receive STEM Network Mini-grants.

AAU universities are engaged in multiple innovative efforts to improve undergraduate education and to help all students succeed. For example,

- department-wide innovations to undergraduate STEM courses are becoming institutional priorities;
- teaching and learning centers are being redesigned to better support department educational reform efforts;

- data infrastructures and analytics are being capitalized on to improve student learning;
- campuses are exploring new hiring practices to advance improvements in STEM education;
- learning spaces are being developed and re-engineered; and
- campuses are addressing the critical challenge of improving the evaluation of faculty teaching.

AAU STEM Project Sites

Central to the project site reforms was the role of the academic department and its faculty members.

Seed-funding was awarded to eight AAU member project sites (Brown University; Michigan State University; The University of Arizona; University of California, Davis; University of Colorado Boulder; University of North Carolina at Chapel Hill; University of Pennsylvania; and Washington University in St. Louis) to implement reforms that address the core elements of the Framework and specific challenges facing their campus in undergraduate STEM education.

- Over three academic years the eight STEM Project Sites have engaged 39 departments, reformed 162 courses, involved 230 faculty members and 1,676 learning assistants (graduate and undergraduate), and transformed STEM courses for 138,531 student-seats.
- Project sites reported trends toward improved learning gains, decreased failure rates, improved persistence from introductory to later courses, and narrowing achievement gaps especially for women, under-represented minorities, and first-generation college students.
- All project sites increased the number of courses targeted for reform based on evidence-based pedagogy, and increased the number of faculty members (tenure-track and non-tenure track) participating. One-half of project sites expanded their reach to additional departments which were not originally included in their proposals. One-half of project sites developed and disseminated common tools used to assess teaching and instruction. Additionally, several project sites linked co-curricular activities with reformed courses to increase retention in STEM majors.
- Across the eight project sites, use of graduate and undergraduate assistants in active learning classes more than doubled, from 740 to 1,676, during the three years of the AAU project. Inclusion of undergraduate and graduate students in instructional roles has benefits for institutions at the level of the course or section. With more trained individuals in the room, the capacity to facilitate and evaluate evidence-based pedagogy increases. The experience also benefits the students themselves by reinforcing core concepts and helping them to learn effective teaching practices.

Examining the Impact

Evaluation is a key component of the Initiative.

AAU is assisting member universities in tracking the progress of their reform efforts in addition to evaluating the overall impact of the STEM Initiative.

- To document cross-institutional effects, AAU collected data from all project sites over a three-and-a-half-year period. Common data collection included a survey of instructor attitudes and practices in participating departments; department chair narratives on policy and practice to assess teaching in the promotion and tenure process; and campus and department level assessment of learning spaces. Findings are presented on pages 60-61, 82-83, 89.

- AAU collected annual reports and conducted two site visits at each of the eight project sites to allow for a more qualitative evaluation of project implementation and progress. In total, AAU met and talked with 325 individuals across the eight project sites. Information from site visits, common data collection, and project site reports are among the sources used to provide much of the detailed analysis found in Section 2.

- In partnership with Adrianna Kezar, Professor, Rossier School of Education and Co-Director, Pullias Center for Higher Education at the University of Southern California, AAU has examined the role that a national higher education association can play in promoting and scaling systemic institutional reforms in undergraduate teaching and learning. A summary of the project is on pages 124-125.

Progress Toward Institutional Change

AAU universities are successfully implementing strategies to achieve long-lasting improvements in undergraduate STEM teaching and learning.

Based upon a comprehensive review of the undergraduate STEM education reforms occurring at AAU universities, we found the following key elements at various institutional levels to be important factors in improving the quality and effectiveness of undergraduate STEM teaching and learning.

- **Shift from individual to collective responsibility by departments for introductory course curriculum.** AAU has observed that departments most likely to emphasize evidence-based active-learning strategies in foundational courses have thought deeply about the curricula and content of these courses, along with ways to assess student learning. Ultimately, collective responsibility for shared learning objectives by course will necessitate developing a uniform vision of educational improvement among faculty members within and across departments, as well as the development of mechanisms to assess progress in teaching effectiveness for all students.

- **Hire educational experts within departments to bolster reforms.** One strategy to successfully institutionalize reform is to embed instructional expertise within the department to provide educational leadership and to support all faculty members in the adoption and use of evidence-based pedagogy. Although the types of appointments of individuals with this type of expertise vary widely (e.g., tenure-track, non-tenure track, junior and senior ranks), these individuals all have in common an understanding of the discipline and how students learn best within the discipline. When used most effectively, these individuals are well positioned to provide educational leadership to the department.

- **Harness institution-wide data to support student learning.** Research universities can greatly facilitate STEM education improvement by supporting the development and use of institution-wide data and analytical tools on student instruction and learning outcomes. Keys to successful use of data analytics include: 1) distinguishing between the types of data useful for individual faculty members designing and assessing their courses and the types of data used in departmental decision-making; 2) the ease and efficiency of use are essential to broad acceptance of teaching-related metrics; and 3) data should not be seen as sufficient in their own right but must be used to help make decisions and establish policies aimed at advancing educational improvement.

- **Reorganize administrative support services to better support departmental reform efforts.** Another key to successful institutionalization of undergraduate instructional reforms is to align relevant administrative units, such as Centers for Teaching and Learning, with department-based instructional improvement efforts. Providing college or campus-wide structures to support departmental reform efforts increased the likelihood of institutionalization in AAU project sites.

- **Develop and re-engineer learning spaces.** Creating collaborative learning spaces to support evidence-based pedagogy has been a catalyst for faculty members to reflect on how they teach their courses. Students have also attributed learning gains to classroom environments that foster engagement and interaction.

- **Better manage the simultaneous pursuit of high quality teaching and research.** The development and use of more effective ways to evaluate teaching quality and effectiveness in the faculty reward structures will be required to institutionalize STEM educational reforms.

- **Commit to systemic and long-term STEM reforms.** Institutionalizing reforms of undergraduate STEM education at research universities eventually requires internal institutional investment and alignment of resources; it cannot be achieved solely by a series of isolated externally-funded grants. Public pronouncements of support for these undergraduate reforms by university leaders also contributes to the spread of instructional reforms across departments. Without further institutional commitment, however, such pronouncements fail in achieving meaningful and long lasting reform.

- **Leverage AAU to advance educational reforms and institutional change.** AAU involvement has symbolic implications that can help campuses achieve cultural and institutional change by providing legitimacy to STEM education reform efforts.

Resources for Universities

AAU has developed resources to help research universities take a systems perspective to improving undergraduate STEM education.

To help facilitate institutional change, key resources and tools have been developed. These include:

- The *Framework for Systemic Change in Undergraduate STEM Teaching and Learning* provides a change model for improving the quality and effectiveness of STEM teaching and learning at research universities.[3] The Framework recognizes the wider setting in which educational innovations take place — the department, the college, the university and the external environment — and addresses key institutional elements necessary for sustained improvement to undergraduate STEM education.

- *Essential Questions and Data Sources for Continuous Improvement of Undergraduate STEM Teaching and Learning* helps member campuses track the progress of their reform efforts.[4] This resource complements the Framework and provides a set of key questions designed to engage institutional leaders and faculty members in discussions about teaching and learning. The report also provides data sources and analytical tools available to answer these questions and inform decision-making, as well as provides guidance to address common challenges in evaluating the quality and effectiveness of undergraduate education.

- *Aligning Practice to Policies* provides specific guidance to departments and institutions on how to implement new methods for evaluating, recognizing, and rewarding teaching at research universities, particularly relating to how teaching is judged for purposes of promotion, tenure, and annual reviews.[5] This resource was developed in collaboration with the Cottrell Scholars funded by Research Corporation for Science Advancement.

3 Association of American Universities (AAU), Framework for Systemic Change in Undergraduate STEM Teaching and Learning (Washington, DC: AAU, 2013).
4 Association of American Universities (AAU), Essential Questions and Data Sources for Continuous Improvement of Undergraduate STEM Teaching and Learning (Washington, DC: AAU, 2017).
5 Association of American Universities (AAU), Aligning Practice to Policies: Changing the Culture to Recognize and Reward Teaching at Research Universities (Washington, DC: AAU, 2017).

Sustaining the Momentum

AAU is committed to improving STEM education at research universities.

AAU leadership has committed to extend the initial five-year undergraduate STEM effort indefinitely by integrating continued support for undergraduate STEM education reform and improvement into its ongoing staffing structure and portfolio of work. AAU will also look to broaden its efforts to improve undergraduate instruction beyond STEM fields in the future.

- A major award provided an additional 24 AAU universities with institutional mini-grants to further advance and coordinate existing efforts aimed at improving undergraduate STEM teaching and learning.

- AAU actively engages a broader network of faculty members and administrators at AAU universities committed to improving undergraduate STEM teaching and learning. The AAU Undergraduate STEM Education Network has convened conferences annually to discuss innovative practices to improve STEM education and hosted a variety of targeted workshops to address critical issues. A workshop, convened by AAU, brought together STEM department chairs from AAU universities to share information about and discuss improving STEM teaching within their departments and recognizing and rewarding faculty members for the quality and effectiveness of their teaching. Moving forward AAU will convene the AAU Undergraduate STEM Education Network and STEM Department Chairs on alternating years.

- AAU will continue to collaborate with other national associations, organizations, funders, and industry partners to coordinate activities relating to undergraduate STEM reform and to develop effective means to disseminate promising and effective programs, approaches, methods, and strategies. The Initiative is engaging multiple stakeholders to promote long-lasting reform to undergraduate STEM education and working to address the cultural and policy barriers within research universities that hamper educational improvement and innovation.

- In partnership with federal agencies, AAU is finding new ways to engage faculty members to broaden the impact of their research by becoming more innovative in the classroom, teaching more effectively, and providing for authentic research experiences to undergraduate students.

- An ongoing examination of how universities can successfully coordinate multiple undergraduate STEM education reforms to achieve sustainable change is underway. This project is designed in recognition of the reality that many AAU universities are advancing multiple department-level as well as institution-wide efforts to improve undergraduate STEM teaching and learning. ■

Report Road Map

Section **1**

Section 1 provides information about the approach and process undertaken by AAU to develop, launch, and implement an initiative in collaboration with our member universities to improve the quality and effectiveness of undergraduate teaching and learning in science, technology, engineering, and mathematics (STEM) fields.

Section **2**

Section 2 provides detailed description and analysis of the eight seed-funded AAU STEM project sites. Included in this section are cross-cutting strategies aligned to core elements of AAU's *Framework for Systemic Change in Undergraduate STEM Teaching and Learning* and a number of vignettes profiling specific institutional approaches and supporting evidence of their impact.

Section **3**

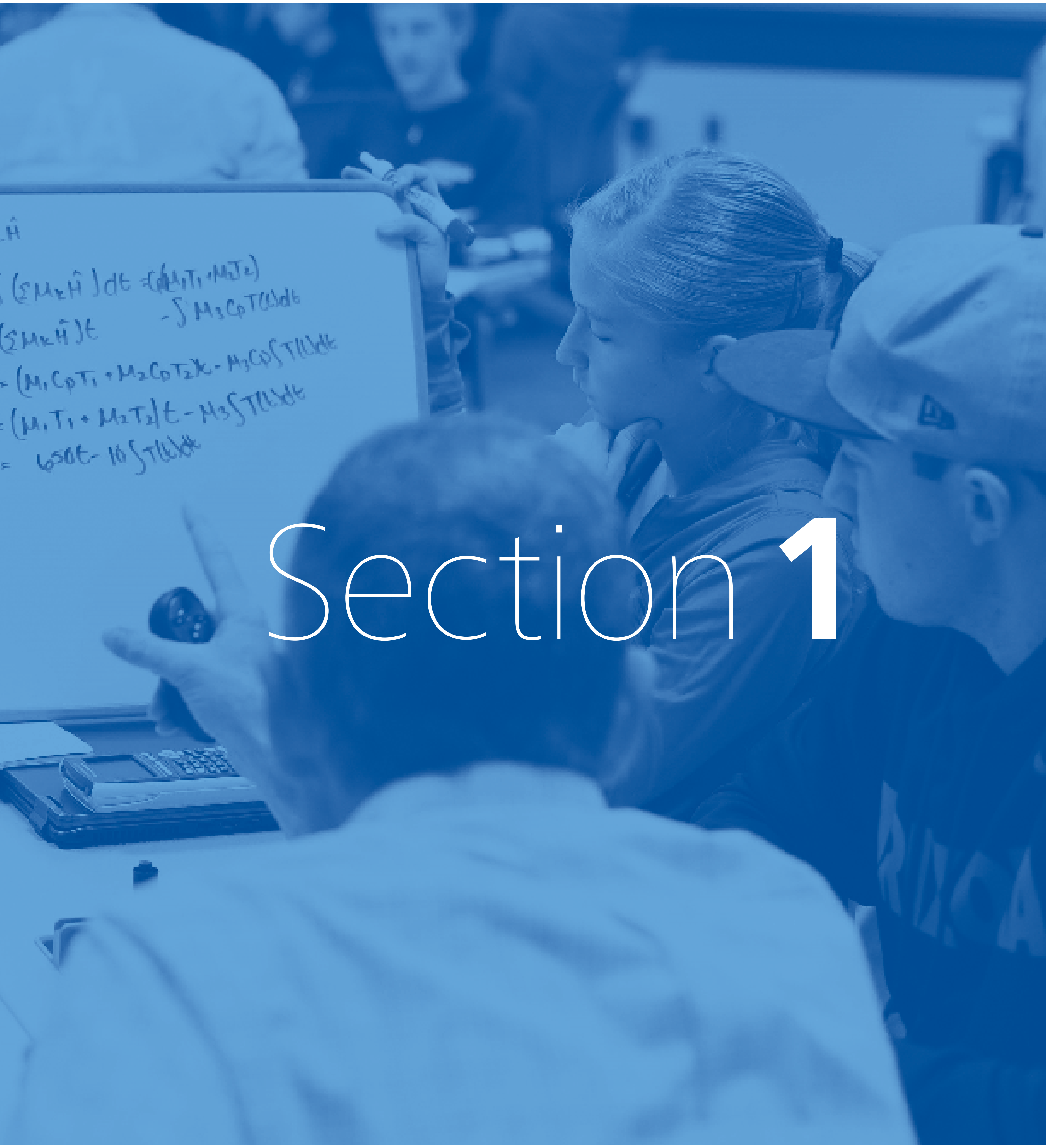
Section 3 discusses the broader AAU STEM Network and highlights additional institutional commitments to advancing the goals of the Initiative.

Section **4**

Section 4 examines both evidence of and keys to successful institutionalization of undergraduate STEM education reforms at two levels – the campus and AAU as an association.

Online **Appendix**

The online appendix contains numerous documents used to implement the Initiative. Throughout the four sections of the report specific appendix materials are referenced. www.aau.edu/STEM/online-appendix



Section 1

Timeline

	2011	2012	2013
AAU Activities **2010** Informal survey of AAU university undergraduate STEM retention programs.	**June** Hunter R. Rawlings, III becomes AAU President. **July** Foundational work is carried out to define the AAU Undergraduate STEM Education Initiative. A matrix of undergraduate STEM reform efforts is developed, a discussion draft disseminated, and an advisory committee formed. **September** The AAU STEM Initiative is publicly announced. **October** Advisory committee conference call.	**February** Advisory committee in-person meeting. **April** AAU asks member Presidents/Chancellors to appoint a campus liaison for the AAU STEM Initiative. **May** Coalition for Reform of Undergraduate STEM Education convenes higher education associations engaged in improving undergraduate STEM education. **November** Emily Miller joins AAU as Project Manager for AAU STEM Initiative.	**March** Advisory committee in-person meeting. **September** Advisory committee conference call.
Framework	**November** AAU starts to develop a Framework to guide the Initiative.	**October** AAU requests feedback by member universities on draft Framework.	**January** AAU's *Framework for Systemic Change in Undergraduate Teaching and Learning* is finalized.
AAU STEM Project Sites & Network			**February** Call for AAU STEM Initiative Project Site concept paper submissions. **June** Eight project sites are awarded and announced. **July** AAU STEM Network conference. Development of cross-instutional measures and metrics to support the multi-instutional evaluation of project sites. **September** First round of campus visits to project sites commence. Feedback sought on common data measures and metrics from project site teams.

2014	2015	2016	2017 and beyond
March Advisory committee conference call. **July** aau.edu/stem website launched. **September** AAU in collaboration with Adrianna Kezar, University of Southern California Professor of Higher Education began to examine the role of a national association in scaling institutional reforms to STEM education.	**August** Advisory committee in-person meeting.	**June** Mary Sue Coleman becomes AAU President.	**May** Advisory committee in-person meeting.
			June *Essential Questions and Data Sources for Continuous Improvement of Undergraduate STEM Teaching and Learning* is released by AAU.
February Request for common data from project sites—Time Point 1. **May** Workshop for project site teams held at AAU. **July** AAU STEM Network conference.	**April** Flex travel grants offered to project sites. AAU hosts a workshop for AAU STEM department chairs. **September** Second round of visits to project sites by the AAU STEM Initiative team commence. **October** AAU STEM Network conference co-hosted with WashU.	**July** No-cost extensions issued to all eight project sites for 4th year. **September** Request for common data from project sites–Time Point 2.	**January** AAU STEM Network mini-grant projects on 12 campuses awarded. **March** AAU receives final reports from project sites. **October** AAU STEM Network conference.

Timeline

	2011	2012	2013
Institutional Reward Structures			
Federal Policies			
Dissemination	**2011–Present** Over 50 presentations to disciplinary societies, federal agencies, Congress, higher education institutions and associations, and national coalitions and networks working to improve undergraduate education.	**May** The National Academies' practitioner guide to the DBER report profiles the AAU Undergraduate STEM Education Initiative.	
Funding Sources		**May** Sponsored by Research Corporation for Scientific Advancement (RCSA), AAU hosts a meeting for funders to learn more about the STEM Initiative, $15K. **October** The Leona M. and Harry B. Helmsley Charitable Trust, $5M for 3 years.	**May** National Science Foundation WIDER, $295K for 2.5 years. **August** RCSA Cottrell Scholars Collaborative, $25K for 2 years. **July** The Burroughs Wellcome Fund, $50K for 1 year.

2014	2015	2016	2017 and beyond
January AAU and RCSA Cottrell Scholars host a workshop on the evaluation of teaching.		**May** AAU and RCSA Cottrell Scholars host a workshop on aligning policy and practice to promote effective evaluation of teaching.	
		October AAU responds to the White House Office of Science and Technology Policy's Active Learning Call to Action. **December** American Innovation and Competitiveness Act addition of "and instruction" updates NSF's broader impacts criteria.	
September Presentation at AAU Provost meeting about institution-wide data and analytics. **October** Coalition for Reform of Undergraduate STEM Education releases *Sourcebook on Achieving Systemic Change.* **December** *The New York Times* publishes an article about the AAU Undergraduate STEM Education Initiative.	**July** AAU & RCSA publish *Searching for Better Approaches: Effective Evaluation of Teaching and Learning in STEM.* AAU & RCSA Cottrell Scholars publish comment article in *Nature.* **August** *Inside Higher Ed* publishes an article about the AAU Undergraduate STEM Education Initiative. **October** Chapters focusing on the work of the AAU Undergraduate STEM Education Initiative are published in *Transforming Institutions: Undergraduate STEM Education for the 21st Century.*		**February** AAU & RCSA publish *Improving Undergraduate STEM Education at Research Universities: A Collection of Case Studies.* **July** AAU & RCSA Cottrell Scholars publish *Aligning Practice to Policies: Changing the Culture to Recognize and Reward Teaching at Research Universities.* **September** AAU staff publish *Catalyzing Institutional Transformation: Insights from the AAU STEM Initiative* in *Change: The Magazine of Higher Learning*.
September 2014 National Science Foundation IUSE, $600K for 3 years.	**April** AAU Department Chair workshop sponsored by Elsevier, $10K. **August** RCSA Cottrell Scholars Collaborative II, $25K for 2 years.	**January** The Leona M. and Harry B. Helmsley Charitable Trust, $240K for 1.5 years. **November** Northrop Grumman Foundation, $1M for 4 years. **October** National Science Foundation IUSE, $700K for 3 years.	

THE CHALLENGE

90%

of students who switched out of STEM fields cited poor teaching as a concern.[7]

THE IMPORTANCE

It is important that students, who will be our future workforce and leaders, are educated using the most effective methods in STEM education.

THE NEED FOR IMPLEMENTATION

The **biggest barrier** to improving undergraduate STEM education is the lack of knowledge about how to effectively **spread the use** of currently available and tested **research-based instructional ideas and strategies**.

AAU Frames the Problem

The impetus for AAU to undertake a national initiative to improve the quality and effectiveness of undergraduate STEM education at research universities was several-fold.

It was grounded in an increasing national focus on STEM education combined with a set of high level policy reports calling for improvements in undergraduate STEM education, a growing body of scholarship on teaching and learning in the STEM fields, and concern that research universities were particularly vulnerable to public criticism about the quality and effectiveness of undergraduate STEM teaching. Of particular concern were the high attrition rates of undergraduate students at major research universities who would declare STEM majors but who would subsequently drop out of STEM fields or fail to complete a degree in any field, with many of them attributing their decisions in part to the poor quality of faculty instruction.

At the time AAU initiated its efforts, many students who intended to major in a STEM field were not completing their degrees, or completing degrees in non-STEM disciplines. According to National Science Foundation (NSF) data, university enrollments continue to increase, as do numbers of bachelor's degrees awarded in both STEM and non-STEM fields. However, STEM degrees as a proportion of total bachelor's degrees have remained relatively constant at about 15-17 percent. Moreover, the proportion of freshmen intending to major in STEM fields exhibits a similar pattern, remaining relatively constant at around 25 percent over the past 15 years. This gap between the percentage of freshmen who intend to major in STEM fields and the percentage of awarded bachelor's degrees in those fields is a persistent trend.

In the 2005 Survey of the American Freshman, as reported by the House Science Committee, half of all students who began in the physical or biological sciences and 60 percent of those in mathematics dropped out of these fields by their senior year, compared with a 30 percent drop-out rate in the humanities and social sciences.[6] According to *Talking About Leaving: Why Undergraduates Leave the Sciences*, by Elaine Seymour and Nancy M. Hewitt, 44 percent of entering freshmen in 1987 who intended to major in a STEM field switched to a non-STEM major by 1991 (this percentage varies somewhat among specific STEM disciplines); for non-STEM majors, only about 30 percent switched to another group of majors.[7] The Higher Education Research Institute (HERI) reported that only 38 percent of students who entered STEM bachelor's programs in the 1993-1994 academic year earned a bachelor's degree in a STEM field within six years. The HERI analysis also showed that, across all races, students who started in STEM fields were less likely to complete degrees in any field than students who intended to major in non-STEM fields.[8]

AAU reflected on the question: Why do so many students who enter college intending to major in a STEM discipline fail to earn a bachelor's degree in STEM? As reported by the Information Technology and Innovation Foundation (ITIF), several studies have shown that most students who leave STEM do so between the first and second year, rather than later in their college career. Seymour and Hewitt surveyed students and obtained the now-infamous result that 90 percent of students who switched out of STEM fields cited poor teaching as a concern. ITIF summarizes Seymour and Hewitt's results: "Of the 23 most commonly cited reasons for switching out of STEM, all but 7 had something to do with the pedagogical experience." Undergraduate teaching was clearly a major factor in students choosing to leave STEM fields, and because most students who leave STEM do so during the first two years of college, those years are especially critical in terms of teaching.

This pattern continues to be borne out by more recent data and reports. According to a National Center for Education Statistics (NCES) study that examined attrition rates in STEM majors for students who began college in the 2003-2004 academic year, 48% of students who entered a bachelor's degree program in STEM between 2003 and 2008 had left STEM fields by spring 2009.[9] Roughly half of these leavers switched their major to a non-STEM field, and the others exited college before earning a degree.

The National Research Council appointed the Committee on Barriers and Opportunities in Completing 2-Year and 4-Year STEM Degrees to address the barriers that prevent students from earning the STEM degrees to which they aspire and to identify opportunities to promote completion of undergraduate

6 US House of Representatives Committee on Science and Technology, Hearing Charter: Strengthening Undergraduate and Graduate STEM Education (Washington, DC, February 4, 2010).

7 Elaine Seymour and Nancy M. Hewitt, Talking about Leaving: Why Undergraduates Leave the Sciences (Boulder, CO: Westview Press, 1997).

8 Higher Education Research Institute (HERI), Degrees of Success: Bachelor's Degree Completion Rates among Initial STEM Majors (Los Angeles, CA: HERI, 2010).

9 National Center for Education Statistics (NCES), STEM Attrition: College Students' Paths Into and Out of STEM Fields (Washington, DC: NCES, 2013).

STEM degrees.[10] The committee concluded that there is an opportunity to expand and diversify the nation's STEM workforce and STEM-skilled workers in all fields if there is a commitment to appropriately support the diverse, complex pathways students take to earn STEM degrees.

At the same time, AAU staff had long recognized that its member institutions were vulnerable to criticism on undergraduate STEM teaching, learning, and retention such as those raised in the 1998 Boyer Commission Report on educating undergraduates in the research university.[11] Also, the ever-growing national discourse to justify the cost and value of an undergraduate degree at a research university was a topic of discussion among the AAU leadership. STEM fields are critical to generating the ideas, products, and industries that drive our nation's global competitiveness, and with the passage of time, they are becoming even more crucial to our country's success. Therefore, it is important that students, who will comprise our future workforce and leaders, are educated using the best and most effective methods in STEM education. Universities must encourage students who enter college intending to major in a STEM field in their educational pursuits, and support the fundamental STEM literacy of students pursuing non-STEM majors. Moreover, schools must work to broaden participation in STEM fields of study. Institutions have a responsibility to ensure that any of their students can learn in STEM classrooms and pursue careers in STEM fields if they desire to do so.

The latest research on teaching and learning has also led to the development of instructional methods that are more engaging and effective at helping students learn. This effect has been extensively documented in STEM fields.[12, 13] A comprehensive meta-analysis of 225 studies revealed that undergraduate students in classes with traditional lectures are 1.5 times more likely to fail than students in classes that use active learning methods.[14] Also, a growing body of evidence demonstrates that learning gains from using these teaching approaches in highly structured classrooms are particularly good for students from disadvantaged and diverse backgrounds and that

A comprehensive meta-analysis of 225 studies revealed that undergraduate students in classes with traditional lectures are 1.5 times more likely to fail than students in classes that use active learning methods.

10 National Academies of Sciences, Engineering, and Medicine (NASEM), Barriers and Opportunities for 2-Year and 4-Year STEM Degrees: Systemic Change to Support Students' Diverse Pathways (Washington, DC: National Academies Press, 2016).

11 Boyer Commission on Educating Undergraduates in the Research University, Reinventing Undergraduate Education: A Blueprint for America's Research Universities (Stony Brook, NY, 1998).

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

13 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).

14 Scott Freeman, et al., Active Learning Increases Student Performance in Science, Engineering, and Mathematics, *Proceedings of the National Academy of Sciences of the United States of America* 111 (2014): 8410–8415.

active learning confers disproportionate benefits for female students in male-dominated fields.[15–18]

Furthermore, the national policy environment has begun to reflect a more coordinated effort to improve undergraduate STEM education across relevant organizations and actors.[19–24] There has been a shift away from isolated directives within individual disciplines and nationally funded efforts that do not require long-lasting reforms within academic institutions. Today many funders are designing solicitations with expectations for projects to build and sustain institutional change.[25]

As AAU reflected on STEM undergraduate education in the 2009-2012 timeframe, it found that despite the problem of students leaving STEM fields and the movement toward developing and supporting systemic reform in STEM undergraduate education to address growing public pressures, a majority of university STEM faculty members who teach undergraduate science and engineering classes remained inattentive to the shifting landscape. Student-centered, evidence-based teaching practices were not yet the norm in most undergraduate STEM education courses, and the desired magnitude of change in STEM pedagogy had not materialized.[26–29]

A principal reason for the lack of widespread pedagogical reform in STEM is the use of theoretical perspectives whose focus is primarily on individual faculty members and the students in their classrooms.[30] Much of this literature

15 Sarah L. Eddy, and Kelly A. Hogan, Getting Under the Hood: How and For Whom Does Increasing Course Structure Work? *CBE-Life Sciences Education* 13 (2014): 453-468.

16 David C. Haak, Janneke HilleRisLambers, Emille Pitre, and Scott Freeman, Increased Structure and Active Learning Reduce the Achievement Gap in Introductory Biology, *Science* 332 (2011): 1213–1216.

17 Kyle F. Trenshaw, David M. Targan, and James M. Valles, Closing the Achievement Gap in STEM: A Two-Year Reform Effort at Brown University, *Proceedings of the American Society for Engineering Education Northeast Section Conference* (2016): 1-9.

18 Mercedes Lorenzo, Catherine H. Crouch, and Eric Mazur, Reducing the Gender Gap in the Physics Classroom, *American Journal of Physics* 74 (2006): 118–122.

19 American Association for the Advancement of Sciences (AAAS), Vision and Change in Undergraduate Biology Education: A Call to Action (Washington, DC: AAAS, 2009).

20 Jodi L. Wesemann, and Mary M. Kirchoff, Chemistry Education: Transforming the Human Elements (Washington, DC: Association of American Colleges & Universities, 2011).

21 American Society of Engineering Education (ASEE), Transforming Undergraduate Education in Engineering: Phase 1: Synthesizing and Integrating Industry Perspectives (Arlington, VA: ASEE, 2013).

22 National Research Council (NRC), A New Biology for the 21st Century (Washington, DC: National Academies Press, 2009).

23 National Research Council (NRC), The Mathematical Sciences in 2025 (Washington, DC: National Academies Press, 2013).

24 National Science and Technology Council (NSTC), Federal Science, Technology, Engineering and Mathematics (STEM) Education: 5-Year Strategic Plan (Washington, DC: NSTC, 2013).

25 Catherine L. Fry, Achieving Systemic Change: A Sourcebook for Advancing and Funding Undergraduate STEM Education (Washington, DC: The Coalition for Reform of Undergraduate Education, 2014).

26 Winston A. Anderson, et al., Changing the Culture of Science Education at Research Intensive Universities, *Science* 331 (2011): 152-152.

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

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

29 Melissa Dancy, Charles Henderson, and Julian Smith, Understanding Educational Transformation: Findings from a Survey of Past Participants of the Physics and Astronomy New Faculty Workshop, *Proceedings of the Physics Education Research Conference* (2013): 113-116.

30 Melissa Dancy and Charles Henderson, Beyond the Individual Instructor: Systemic Constraints in the Implementation of Research-Informed Practices, *Proceedings of the Physics Education Research Conference* (2004): 1-4.

Kelly Hogan, STEM Teaching Associate Professor and Assistant Dean of Instructional Innovation, teaching in a high-structure, high-engagement introductory biology classroom at the University of North Carolina at Chapel Hill.

centers on micro-level assessments of the classroom, which is crucial to assessing the effect of pedagogy on student learning. Yet this literature often ignores the larger institutional and external environment and fails to account for the costs and political challenges in scaling up reforms.[31, 32] Concern about more macro-level environments requires a change in assessment from looking solely for benefits and learning outcomes at the course or program level to a more nuanced consideration of factors that facilitate, impede, or influence wide-spread transformation in undergraduate STEM education.

To increase the implementation and widespread adoption of instructional strategies shown to be effective requires a model of change that includes the roles of research evidence, leadership, resources, faculty workload and rewards, and faculty professional development. In this context, empirical evidence is only one part of the reform effort. As Fairweather has explained, "research evidence of instructional effectiveness is a necessary but not sufficient condition" for faculty to change their teaching practices. Fairweather suggests that the assumption that "the instructional role can be addressed independently from other aspects of the faculty position, particularly research, and from the

31 P. David Fisher, James S. Fairweather, and Marilyn J. Amey, Systemic Reform in Undergraduate Engineering Education: The Role of Collective Responsibility, *International Journal of Engineering Education* 19 (2003): 768-776.

32 Charles Henderson and Melissa 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).

larger institutional context" is misguided.[33] Given the size and scale of higher education, changing individual faculty members or even isolated departments will have minimal impact. To achieve long-lasting and broadly disseminated educational reforms, efforts must go well beyond this micro-level focus on faculty members.

Scholars recommend that sustainable STEM education reform requires engaging institutional leaders such as department chairs, deans, and presidents in rethinking institutional structures and culture.[34] A recent case study of undergraduate STEM education reform conducted at the University of Colorado Boulder found that top-down (campus-level academic leaders) and bottom-up (faculty) reforms alone are inadequate for sustained institutional improvement in undergraduate education; middle-out (chairs, college deans) reforms are also required.[35] Austin's well-documented systems approach to change also suggests that external stakeholders such as disciplinary societies, government agencies, and employers are crucial to long-lasting change.[36] In sum, transforming undergraduate STEM education requires multiple facilitators or "levers" pushing for change that can counterbalance the forces that sustain ineffective instructional practices and address the obstacles inherent in the system in which educational innovations take place.[37–39]

AAU's approach of developing a shared priority among multiple stakeholders rather than only individual faculty members offers a potentially transformative approach to STEM education reform.

The AAU Undergraduate STEM Education Initiative launched in 2011 is specifically aimed at assisting AAU institutions to implement what we already know works in STEM education, and assuring that these teaching practices are widely implemented in STEM departments to support the learning and persistence of students in STEM on a large scale. AAU's approach of

33 James Fairweather, Linking Evidence and Promising Practices in Science, Technology, Engineering, and Mathematics (STEM) Undergraduate Education, white paper commissioned for the National Academies National Research Council Board of Science Education Workshop: Evidence on Promising Practices in Undergraduate Science, Technology, Engineering, and Mathematics (STEM) Education (October 13-14, 2008).

34 Ann E. Austin, Barriers to Change in Higher Education: Taking a Systems Approach to Transforming Undergraduate STEM Education, white paper commissioned for the Coalition for Reform of Undergraduate STEM Education Foundation Workshop on Transforming Undergraduate STEM Education (June 17-19, 2013).

35 Joel C. Corbo, Daniel L. Reinholz, Melissa H. Dancy, Stanley Deetz and Noah Finkelstein, Sustainable Change: A Model for Transforming Departmental Culture to Support STEM Education Innovation, arXiv:1412.3034 (December 9, 2014).

36 Ann E. Austin. (2011). Promoting Evidence-Based Change in Undergraduate Science Education, paper commissioned for the Board on Science Education of the National Academies National Research Council (March 1, 2011).

37 Winston A. Anderson, et al., Changing the Culture of Science Education at Research Intensive Universities, *Science* 331 (2011): 152-152.

38 Andrea L. Beach, Charles Henderson and Noah Finkelstein, Facilitating Change in Undergraduate STEM Education, *Change: The Magazine of Higher Learning* 44 (2012): 52-59.

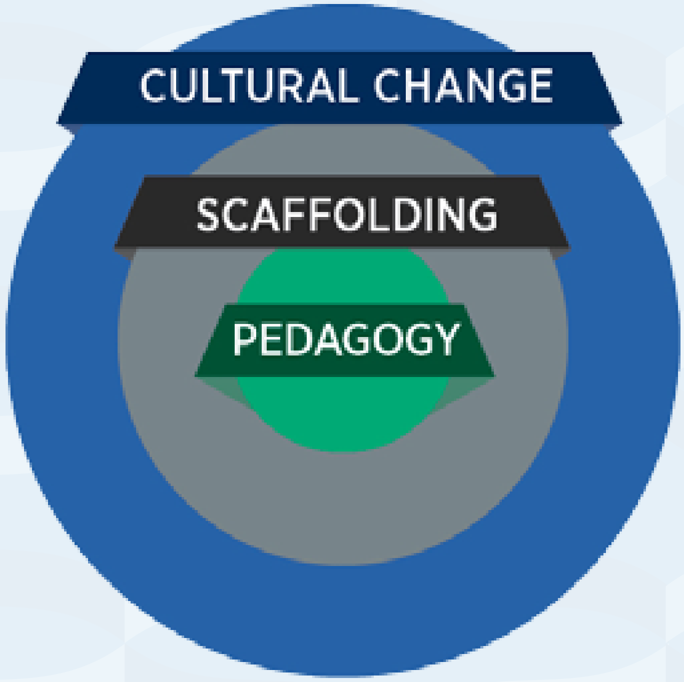
39 Susan Elrod and Adrianna Kezar, Increasing Student Success in STEM: A Guide to Systemic Institutional Change (Washington, DC: Association of American Colleges & Universities, 2016).

developing a shared priority among multiple stakeholders rather than only individual faculty members offers a potentially transformative approach to STEM education reform.

This ambitious project, which seeks to increase the importance of undergraduate STEM education in the nation's top research universities, is promoting the implementation of a more systemic view of educational reform within academia.[40]

40 National Research Council (NRC), Designing Learning: A National Organization Leverages Systemic Change in STEM Teaching and Learning in Reaching Students: What Research Says about Effective Instruction in Undergraduate Science and Engineering (Washington, DC: National Academies Press, 2015), 203-204.

INSTITUTIONAL CHANGE MODEL

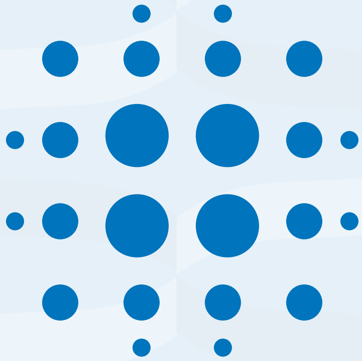


CAMPUS ENGAGEMENT

42

AAU member universities convened teams to review and refine the Framework.

SYSTEMS APPROACH



The **Framework** provides a set of key elements that need to be addressed to bring about sustainable change at an institutional level.

AAU Takes a Systems Perspective

The AAU STEM Initiative from the beginning has been informed by broader theoretical perspectives about organizational change in academia and about faculty work and rewards.

AAU's *Framework for Systemic Change to Undergraduate STEM Teaching and Learning* recognizes the wider setting in which educational innovations take place — the department, the college, the university and the external environment — and addresses key institutional elements necessary for sustained improvement to undergraduate STEM education.[41] The Framework was developed in collaboration with member universities.

The core of AAU's Framework is pedagogy: the practices used by faculty members to engage students and guide and support their learning. To successfully enact and institutionalize the use of evidence-based teaching techniques, two layers around this pedagogical core are necessary: scaffolding, or support, for both faculty and students, and larger cultural change to facilitate changing teaching practices. Ultimately, the Framework provides a set of key elements that need to be addressed to bring about sustainable change at an institutional level.

41 Association of American Universities (AAU), Framework for Systematic Change in Undergraduate STEM Teaching and Learning (Washington, DC: AAU, 2013).

KEY INSTITUTIONAL ELEMENTS

Pedagogy

- Articulated Learning Goals
- Educational Practices
- Assessments
- Access

Scaffolding

- Provide Faculty Professional Development
- Provide Faculty with Easily Accessible Resources
- Collect & Share Data on Program Performance
- Align Future Facilities Planning

Cultural Change

- Leadership Commitment
- Establish Strong Measures of Teaching Excellence
- Align Incentives with the Expectation of Teaching Excellence

The Framework addresses organizational change at two levels—broadly, at the multi-institutional level and locally, at the university or college level. From a multi-institutional perspective, the Framework provides a commitment to a systems approach to change and a unifying goal, one that includes a shared understanding of the challenges and a set of key institutional elements that must be addressed to bring about sustainable change.[42–44] Yet, the Framework allows for universities and colleges to use diverse strategies and approaches to achieve the common goal, as different strategies and approaches will be effective for achieving systemic improvement in STEM teaching and learning at different institutions. Thus, the Framework is highly adaptable and respects local institutional culture and history. Visit aau.edu/STEM to see examples of innovative institutional efforts and how they are mapped to elements of the Framework.

The Framework has proved central to several elements of the AAU Initiative, from guiding campus thinking to selection of the funded and highly visible project sites to recent efforts to organize information about resources available to campuses to facilitate continued conversation about change, especially surrounding the need for continual assessment of reform efforts. ■

42 John Kania and Mark Kramer, Collective Impact, *Stanford Social Innovation Review* 9 (2011): 36-41.

43 Susan Elrod and Adrianna Kezar, Increasing Student Success in STEM: A Guide to Systemic Institutional Change (Washington, DC: Association of American Colleges & Universities, 2016).

44 Adrianna Kezar, Sean Gehrke and Susan Elrod, Implicit Theories of Change as a Barrier to Change on College Campuses: An Examination of STEM Reform, The Review of Higher Education 38 (2015): 479-506.

ENGAGEMENT BY AAU UNIVERSITIES

55

AAU member universities have participated in the Initiative

PROJECT SITES

50%

of AAU members submitted concept papers to be considered a project site

NETWORK

A larger community of AAU peers that care about innovations in STEM teaching and learning.

GRANTS

AAU has received **11** grants totaling **$7.9M** from private foundations, corporate foundations, and the federal government to advance the AAU STEM Initiative.

The Role of AAU

Foundational Work

Hunter R. Rawlings III became the president of AAU in June 2011. At his first meeting with staff, he expressed a strong desire for AAU to undertake an initiative to improve STEM education at the undergraduate level at AAU universities. This desire meshed nicely with activities already underway and being actively pursued by Toby Smith, AAU's Vice President for Policy under the leadership of Bob Berdahl, the previous AAU president. These activities included ongoing conversations with Carl Wieman, a Nobel Prize winning physicist with a passion for improving undergraduate STEM education, who had recently been appointed Associate Director for Science at the White House Office of Science and Technology Policy (OSTP); with Linda Slakey, Director of the Division of Undergraduate Education in the Education and Human Resources (EHR) Directorate of the National Science Foundation (NSF); and with the President's Council of Advisors on Science and Technology (PCAST) who had created a working group and were in the midst of conducting their own report on the need to improve undergraduate STEM education. Moreover, Toby had previously conducted a survey of AAU member universities asking them to highlight noteworthy programs in undergraduate STEM education. Results of the survey indicated that most efforts occurred in out-of-classroom or co-curricular activities (e.g., undergraduate research opportunities, bridge programs, living-learning communities, etc.), which, although important, do not address the within-class experiences and the effectiveness of faculty members' instructional practice and student engagement.

During the summer of 2011, Josh Trapani, AAU's Associate Vice President of Research and Policy Analysis, prepared a "discussion draft" in the form of a white paper of a proposal for a five-year initiative to improve undergraduate STEM Education.[45] The discussion draft laid out the problem,

45 Association of American Universities (AAU), Five-Year Initiative for Improving Undergraduate STEM Education: Discussion Draft (Washington, DC: AAU, October 14, 2011).

highlighting the fact that "improving undergraduate teaching is integral to meeting the pressing national need for more STEM majors." The white paper pointed to previous work showing that many students interested in STEM switched to other majors during the first two years of college, and that teaching was one of the main causes for this shift. Cultural factors at research universities worked against instructors incorporating more active learning pedagogy in their classes, even though the evidence base supporting active learning pedagogy held appeal for researchers who were also teachers. The discussion draft laid out five goals, which have continued to guide the Initiative through its subsequent activity.

From the beginning, AAU staff recognized that such an ambitious initiative would not succeed if it were simply an add-on to existing AAU activities. Staff lacked both expertise and bandwidth to perform the work, and the development of a demonstration program required an external funding source. Coincident with producing this discussion draft, AAU staff began to identify individuals who might serve on an advisory committee for the Initiative and help provide expert guidance. The initial membership of the advisory committee included practitioners and leaders in aspects of work related to the goals of the Initiative. The Initiative was announced publicly in September 2011, and the advisory committee held its first meeting, by phone, in October. Many of the individuals on the advisory committee provided critiques of the discussion draft.

Kristen Hodge-Clark, a AAAS Fellow at AAU, gathered data to map major association and disciplinary society efforts in STEM reform and to identify areas of overlap among various organizations. As a part of this effort, AAU developed a matrix of STEM undergraduate education reform efforts at research institutions.[46]

Additionally, AAU drew on the expertise of federal officials and colleagues at other organizations, including associations, disciplinary societies, and funders, in honing the plan for the Initiative. In particular, staff coordinated with two advisory committee members, S. James Gates and Jo Handelsman, who at the time were also serving as co-chairs of the PCAST working group on issues around improving undergraduate STEM education. PCAST's report "Engage to Excel" was released in February 2012 and provided a national-level vision that was consistent with the goals of the AAU Initiative, especially in its focus on the importance of reforming teaching.[47] The advisory committee held its first in-person meeting, also in February. In May, the National Academies released its report on discipline-based education research, which further supported the emphasis on active pedagogy in the Initiative.[48]

46 Association of American Universities (AAU), Matrix of National STEM Undergraduate Education Initiatives (Washington, DC: AAU, December 1, 2011).

47 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).

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

AAU staff began compiling information that was envisioned as useful to developing a framework for institutions to assess and improve the quality of STEM teaching and learning. In placing framework development as the first goal, staff benefited from the example and experience of the Association of Public and Land-grant Universities' (APLU) Science & Mathematics Teacher Imperative (SMTI).[49] The framework was initially envisioned as a lengthy, detailed document and set of resources. The first rough outline of what would be included in a framework was produced in November, 2011. This version received feedback from members of the advisory committee and benefited from the information contained in the PCAST report. It was further revised during the spring and summer, and sent out to AAU member campuses for feedback in October, 2012 [see Online Appendix for request for feedback on the Framework].

During this time-period, the AAU Initiative continued to gain momentum. In April 2012, AAU member university presidents and chancellors were asked at their spring meeting to provide a campus primary point of contact for the Initiative. This person was to be someone to whom the presidents and chancellors would rely on and engage with regarding the AAU Initiative. During that spring, AAU had conversations with numerous potential funders of the demonstration program. The Research Corporation for Science Advancement (RCSA) sponsored a workshop for funders interested in learning more about the AAU Initiative and other initiatives focused on improving undergraduate STEM education. This workshop was held at AAU in May, and attendees included The Leona M. and Harry B. Helmsley Charitable Trust, who were beginning to move into the space of higher education.[50] Over the summer, AAU staff, along with two members of the advisory committee – Linda Slakey and James Fairweather, who served as a co-PI – produced a proposal for The Helmsley Charitable Trust to conduct a demonstration project on AAU campuses. The same group also developed a proposal focused on metrics and evaluation for NSF. Ultimately, both proposals were successful. AAU announced the The Helmsley Charitable Trust grant in October, 2012, and the NSF WIDER grant in May, 2013. [51, 52]

Implementation

In fall of 2012, with The Helmsley Charitable Trust funding secured, AAU hired a full-time project manager for the Initiative. Emily Miller joined AAU in November. Collectively, Toby Smith, Jim Fairweather, Linda Slakey, Josh Trapani, and Emily Miller became the core AAU team responsible for the implementation of the AAU Undergraduate STEM Education Initiative and the corresponding goals. This group has met bi-weekly for a one-hour teleconference, and at least twice a year for a one or two day working session in Washington, DC, since fall of 2012.

49 Association of Public and Land-Grant Universities (APLU), Developing the Analytic Framework: Assessing Innovation and Quality Design in Science and Mathematics Teacher Preparation (Washington, DC: APLU, 2012).

50 The Leona M. and Harry B. Helmsley Charitable Trust

51 Major Grant from Helmsely Charitable Trust Boosts AAU Initiative to Improve Undergraduate STEM Education, AAU press release, October 18, 2012.

52 Grant from National Science Foundation Boosts AAU Initiative to Improve Undergraduate STEM Education, AAU press release, May 6, 2013.

The initial draft Framework was refined based on feedback provided by 42 different AAU member campuses. In response to this feedback, the Framework was transformed from a detailed and proscriptive set of instructions to a concise conceptual document. The final Framework provides a set of key institutional elements that need to be addressed to bring about sustainable change. From a multi-institutional perspective, the Framework provides a shared vision for change, one that includes a common understanding of the challenges and an agreed upon set of institutional elements that must be addressed to bring about sustainable change. Along with the five goals in the discussion draft, the Framework became central to subsequent work.

Collectively the project team developed and implemented a process for selecting project sites funded by The Helmsley Charitable Trust. From the beginning, AAU's approach to the demonstration project involved a balance: taking advantage of the competitive nature of AAU's member universities with one another without creating a two-tiered system that might exclude some institutions to the extent of discouraging them from acting. The project sites were envisioned as one part of a larger STEM Network that included all interested AAU member universities. In February 2013, AAU put out a call for concept papers from schools interested in being part of the demonstration project [see Online Appendix for project site selection process materials]. Thirty-one AAU universities submitted concept papers, which were reviewed using a rubric and narrowed to 11 institutions, who were asked for more detailed plans of work. From these 11, eight project sites were selected in June 2013.[53]

The eight project sites–Brown University; Michigan State University; The University of Arizona; University of California, Davis; University of Colorado Boulder; University of North Carolina at Chapel Hill; University of Pennsylvania; and Washington University in St. Louis–served as laboratories to implement the key elements of the Framework and represented the first phase of encouraging AAU universities to take a systems approach to reform of undergraduate teaching practices. Each of the eight project sites received $500,000 to seed fund projects (Year 1: $250K, Years 2-3: $125K).

It is important to note that these eight universities were not selected because they were the most advanced in terms of activity already focused on improving undergraduate STEM education. AAU made a deliberate decision to create balance among the schools not only in terms of public/private status, region, size, and other factors, but also in terms of proposal objectives and how developed existing STEM teaching reform efforts on campus were. The hope was that the eight project sites could serve as potential models for other institutions, no matter where these others were in terms of emphasis and activity.[54]

53 AAU Selects Eight Campus Project Sites for Undergraduate STEM Education Initiative, AAU press release, June 25, 2013.

54 Emily R. Miller and James S. Fairweather, The Role of Cultural Change in Large-Scale STEM Reform: The Experience of the AAU Undergraduate STEM Education Initiative, in Transforming Institutions: Undergraduate STEM Education for the 21st Century, ed. Gabriela C. Weaver, et al., (West Lafayette, IN: Purdue University Press, 2015): 48-66.

AAU's Initiative also recognized that large-scale improvements require a network through which ideas can travel, be tested, modified, and improved in a continuous cycle of growth. Research by Fairweather and by Eckel and Kezar strongly suggests that evidence alone is not sufficient for sustainable reform.[55,56] Rather, peer relationships and institutional as well as interpersonal networks are crucial factors in changing ideas and practices.[57, 58] Thus, AAU also built into its approach the AAU STEM Network – a collaborative network that would allow AAU institutions that were not project sites to participate in the Initiative. It became clear as the process moved forward that several institutions – both project sites and non-project sites – were serious about advancing educational reforms and interested in learning from other AAU institutions that were tackling similar challenges on their own campuses.

AAU has hosted three STEM Network conferences — in 2013, 2014, and 2015 — with attendees including administrators, faculty members, postdocs, and students from AAU universities. These conferences have given attendees opportunities to showcase their work and learn about the work of others, discuss common themes and challenges, and build relationships across campus roles and institutions. Additionally, AAU frequently hosts workshops to provide in-person forums for all AAU institutions to engage in the Initiative, and AAU brings together on occasion key stakeholders to address specific challenges to implementing institutional efforts to reform STEM teaching and learning for undergraduate students. For example, AAU hosted a two-day workshop in April 2015 for STEM department chairs and faculty members, "Improving Undergraduate STEM Teaching & Learning: The Role of the Department Chair." This workshop, which was sponsored by Elsevier, provided over 100 department chairs, faculty members, and university administrators with an opportunity to discuss introductory curriculum redesign efforts, staffing models for introductory STEM courses, evaluation of department innovations in teaching and learning, and metrics for rewarding teaching.

AAU intentionally built a multi-instutional network aimed at improving the quality and effectiveness of undergraduate STEM education in the nation's top research universities.

To date, 55 (out of 62) AAU member universities have participated in undergraduate reform activities hosted by AAU with involvement from more than 275 faculty members and institutional leaders. In addition, AAU recently awarded 12 mini-grants to universities who are engaged in the AAU

55 James Fairweather, Linking Evidence and Promising Practices in Science, Technology, Engineering, and Mathematics (STEM) Undergraduate Education, white paper commissioned for the National Academies National Research Council Board of Science Education Workshop: Evidence on Promising Practices in Undergraduate Science, Technology, Engineering, and Mathematics (STEM) Education (October 13-14, 2008).

56 Peter D. Eckel, and Adriana Kezar, Taking the Reins: Institutional Transformation in Higher Education (Washington, DC: ACE/Praeger, 2003).

57 Thomas W. Valente, Network Models of the Diffusion of Innovations (Cresskill, NJ: Hampton Press, 1995).

58 Everett M. Rogers, Diffusion of Innovations, 5th Edition (New York, NY: Free Press, 2003).

STEM Network but not part of the original eight project sites. AAU has learned through its STEM Initiative that grants awarded by AAU to member institutions can have powerful symbolic implications that can help campuses facilitate change.

Toby Smith was invited to speak about the AAU Initiative during the 2012 RCSA Cottrell Scholars conference. At the conference, Toby discussed with current and former Cottrell Scholars a major barrier to improving the quality of undergraduate education: the predominant use of student-based evaluations to assess teaching quality at colleges and universities. While effective at assessing faculty popularity, these student evaluations often fail to accurately reflect teaching quality and student learning. The two groups proposed a joint project, which RCSA subsequently agreed to support, aimed at identifying new and innovative means to evaluate and reward teaching quality and effectiveness.

To help to accomplish the goals of this joint project, AAU and a subset of scholars from the RCSA Cottrell Scholars Collaborative held a joint workshop in January 2014 that brought together leading research-active faculty members as well as higher education scholars and practitioners to understand the landscape of established and emergent means to reward teaching more accurately than traditional measures such as student evaluations and to assess how research universities do or do not reward teaching in promotion and tenure decisions. The workshop culminated in a workshop report, *Searching for Better Approaches: Effective Evaluation of Teaching and Learning in STEM* and an article in *Nature* titled, *University Learning: Improve Undergraduate Science Education*.[59, 60] The Cottrell Scholars and AAU were awarded a second collaborative project by RCSA and in May 2016 brought together leading higher education scholars and practitioners as well as research-active faculty members to develop specific recommendations and guidance to value, assess, and reward effective teaching.[61]

In addition to AAU's efforts to try to find ways to better assess and evaluate teaching, AAU has also worked to better leverage existing NSF broader impacts requirements to improve the quality of undergraduate STEM education and to achieve meaningful and long-lasting cultural change.

Currently, all NSF grant proposals are evaluated on two broad-based criteria: their *intellectual merit,* which encompasses the potential to advance knowledge, and their *broader impacts*. The broader impacts criterion encompasses the potential of the work being done associated with the grant to benefit society and contribute to the achievement of specific, desired societal outcomes.

59 Association of American Universities (AAU) and Research Corporation for Science Advancement (RCSA), Searching for Better Approaches: Effective Evaluation of Teaching and Learning in STEM (Tucson, AZ: RCSA, 2015).

60 Stephen E. Bradforth, et al., University Learning: Improve Undergraduate Science Education, *Nature* 523 (2015): 282-284.

61 Association of American Universities (AAU) and Research Corporation for Science Advancement (RCSA), Aligning Practice to Policies: Changing the Culture to Recognize and Reward Teaching at Research Universities (Tucson, AZ: RCSA, 2017).

As a part of 2010 legislation reauthorizing the America COMPETES Act, Congress included eight specific goals for NSF broader impacts criteria. Two of these goals, "improving undergraduate education" and "increasing public scientific literacy," directly relate to the AAU Initiative, and can be used as a tool to encourage faculty to improve the quality of their undergraduate STEM teaching.

There are, however, many challenges in getting faculty members to utilize improving their classroom teaching practices to fulfill their NSF broader impacts requirements. These challenges include the fact that many NSF researchers are unfamiliar with the broader impacts criteria and unaware that improving the quality of their classroom teaching, if done correctly, can count. Still others are skeptical that NSF review panels will view improving how they provide in-classroom instruction in the discipline or field of their NSF funded research as broader impacts.

This concern has some legitimacy because the NSF itself is not very prescriptive in telling review panels how to interpret and assess broader impacts. Additionally, NSF review panels are not always well instructed by their program officers on what counts and how to effectively evaluate broader impacts. Indeed, some faculty members who have included improving in-class teaching of undergraduate students as a broader impact have received negative feedback from NSF reviewers who have specifically suggested in their comments that since 'teaching' is a required part of their faculty work, activities that help to improve instruction should not be included or counted as broader impacts.

To help to address this concern, AAU successfully added clarifying language to the American Innovation and Competitiveness Act (AICA). This legislation, approved by the Congress in late December 2016 and signed into law by the President January 6, 2017, updated the goals for NSF's broader impacts criteria. The new language clearly states that 'improved undergraduate education *and instruction*' are means by which NSF researchers can achieve a broader impact.

Building on this change in the legislation, AAU is working though the National Alliance for Broader Impacts (NABI), the NSF, other scientific organizations and its member institutions to deliver a clear message that the adoption and usage by an NSF awardee of evidence-based and/or active and engaged teaching practices proven to enhance undergraduate learning and understanding of core STEM concepts in disciplines relating on the principal investigator's NSF funded research award should be recognized by NSF review panels as an acceptable form of meeting NSF broader impacts criteria.

Evaluation

Evaluation is a key component of the Initiative. AAU is assisting member universities in tracking the progress of their reform efforts in addition to evaluating the overall impact of the Initiative. In this process, AAU has distinguished between measures that are most meaningful at the department level and those most useful in documenting cross-institutional effects.

To support local assessment, AAU has developed a resource guide, *Essential Questions and Data Sources for Continuous Improvement of Undergraduate STEM Teaching and Learning*.[62] The guide provides a set of key questions designed to engage institutional leaders and faculty members in discussions about teaching and learning. The guide also profiles data sources and analytical tools available to answer these questions and inform decision-making. It further provides guidance to address shared challenges in evaluating the quality and effectiveness of undergraduate education. The *Essential Questions and Data Sources* guide is a complementary resource to the *Framework for Systemic Change in Undergraduate STEM Teaching and Learning*.

To document cross-institutional effects, AAU collected data from all project sites over a three-and-a-half-year period, beginning in the Fall 2013. Common data collection included a survey of instructors in participating departments; department chair narratives on policy and practice to assess teaching in the promotion and tenure process; and campus and department level assessment of learning spaces [see Online Appendix for project site common data collection materials].

To begin developing these cross-institutional quantitative measures, AAU convened a working group of experts on metrics and evaluation in July 2013. Following this meeting, AAU project staff developed a set of research questions mapped to the AAU Framework. AAU decided to collect information on physical infrastructure (using a portion of the PULSE Vision & Change Rubric) and to ask for written descriptions of the role of teaching in promotion and tenure by project leads and department chairs.[63] To assess instructor attitudes and practices, AAU project staff assembled an instrument from existing tools that would be used to survey instructors. Through an iterative conversation with individuals at project sites, AAU arrived at a final instrument, as well as a collective understanding of how AAU would use the data. Results were obtained at two points in time – early 2014 (for the 2013-14 year) and in fall of 2016 (for the 2015-16 year).

Beyond this baseline data request, AAU asked project sites to provide additional information in annual reports. Site-specific data included data on student learning outcomes. AAU asked each project site to provide evidence for enhanced student learning, but did not require the same indicators or metrics to be collected in the same way across the sites [see Online Appendix for project site annual and final report requests]. [64]

62 Association of American Universities (AAU), Essential Questions and Data Sources for Continuous Improvement of Undergraduate STEM Teaching and Learning (Washington, DC: AAU, 2017).

63 PULSE Vision & Change Rubrics

64 James Fairweather, Josh Trapani and Karen Paulson, The Roles of Data in Promoting Institutional Commitment to Undergraduate STEM Reform: The AAU STEM Initiative Experience, in Transforming Institutions: Undergraduate STEM Education for the 21st Century, ed. Gabrielle C. Weaver, et al., (West Lafayette, IN: Purdue University Press, 2015): 429-437.

Integrated with the collection of baseline measures and annual reports, AAU conducted two site visits at each of the eight project sites to allow for a more qualitative evaluation of project implementation and progress [see Online Appendix for project site interview protocols]. In total, AAU met and talked with 325 individuals across the eight project sites. Teams met with campus project leaders, department chairs and deans, and Provosts, using these visits to identify challenges and possible solutions to implementing project activities, and to look at subsequent changes. Site visits also built trust between AAU and project sites. While designed for project site campuses, the components of this evaluation are useful for any institution interested in assessing its progress.

AAU conducted 325 interviews across the eight project sites.

In September 2014, AAU announced it had received a second grant from NSF, this one to examine the role a national association can play in expanding reform efforts aimed at improving the quality of undergraduate teaching and learning in STEM fields at its member institutions.[65] This project is being conducted in partnership with Adrianna Kezar, Professor, Rossier School of Education and Co-Director, Pullias Center for Higher Education at the University of Southern California.

Sustaining the Momentum of the Initiative

AAU found that certain steps taken prior to supporting specific plans for implementation were essential to the Initiative's success. These included developing a shared understanding of the Initiative's goals; collectively developing the Framework; agreeing that multiple-strategies are possible to achieve the Initiative's goals; determining how to assess the Initiative's overall impact; and aligning this effort within the national landscape.

Ultimately the foundational work required to generate buy-in and engagement from member campuses in an initiative of this magnitude is critical. Member universities need the opportunity for teams to participate in the development of a shared vision and framework to ensure that each campus can see their local context within the conceptual change model. Time is also critical to build the trust necessary for campuses to participate in a collective effort, develop a functioning network, and agree to a common data collection effort aimed at measuring aggregate impact.

AAU has successfully established an infrastructure to help align the AAU membership toward a common goal. Each AAU member campus has designated at least one individual as a campus point of contact for the Initiative who acts as a liaison between their campus and AAU on the project. To support the Initiative's activities and goals, the dedicated project director situated at AAU engages in continuous dialogue with AAU member campuses

65 AAU Receives NSF Grant to Study How AAU STEM Teaching Initiative is Producing Educational Change at Member Campuses, AAU press release, September 9, 2014.

Andrea Follmer Greenhoot, Professor of Psychology, Director of the Center for Teaching Excellence and Gautt Teaching Scholar at the University of Kansas, facilitating a knowledge exchange among faculty members around evidence-based educational improvement at a TRESTLE meeting.

along with senior university administrators and designated campus liaisons to coordinate and manage the project. The project director also plays an essential role in writing grants to secure funding for the various activities in support of the Initiative's goals.

AAU also continuously brings to the attention of university leadership (President or Chancellor, and Provost) results from Initiative activities and successful strategies to improve undergraduate STEM education, drawing attention to their own campus-based success stories supporting the AAU Initiative (of which they are often unaware). AAU recognizes that it is critical to have continuous communication and create spaces for relationships and trust among peers to develop. At the same time, AAU leadership and staff have also made it known to campus leaders when they have observed relative inactivity from their particular campus in engaging with the Initiative and/or in focusing attention on improving the quality of undergraduate STEM education.

AAU also collaborates with other national associations, organizations, funders, and industry partners to coordinate activities relating to undergraduate STEM reform and to develop effective means to disseminate promising and effective programs, approaches, methods, and strategies. The Initiative engages multiple stakeholders to promote long-lasting reform to undergraduate STEM education, and it works to address the cultural and policy barriers within research universities that hamper educational improvement and innovation.

In 2016 AAU received two major awards. A grant in the amount of approximately $1 million over four years from the Northrop Grumman Foundation will support institutional mini-grants to further advance and coordinate existing efforts aimed at improving undergraduate STEM teaching and learning. AAU will award two rounds of twelve mini-grants designed to further existing efforts to improve undergraduate education. The first cohort was announced in January 2017 and will fund specific improvements in individual departments or across colleges at the selected universities. Efforts include creating learning communities for STEM faculty members involved in reform efforts, establishing programs to train graduate students and undergraduate teaching assistants or peer advisors in active learning practices, developing college wide teaching evaluation programs, implementing an educational analytics program for the university, and supporting STEM course redesigns.

A grant in the amount of approximately $700K over three years from the NSF will allow AAU to examine the institutional landscape in which STEM innovations take place to better understand how universities align their various projects to promote long-lasting reform to undergraduate STEM education. This project led by Emily Miller, James Fairweather and Mary Deane Sorcinelli is designed in recognition of the reality that many AAU universities are advancing multiple department-level as well as institution-wide efforts to improve undergraduate STEM teaching and learning. ■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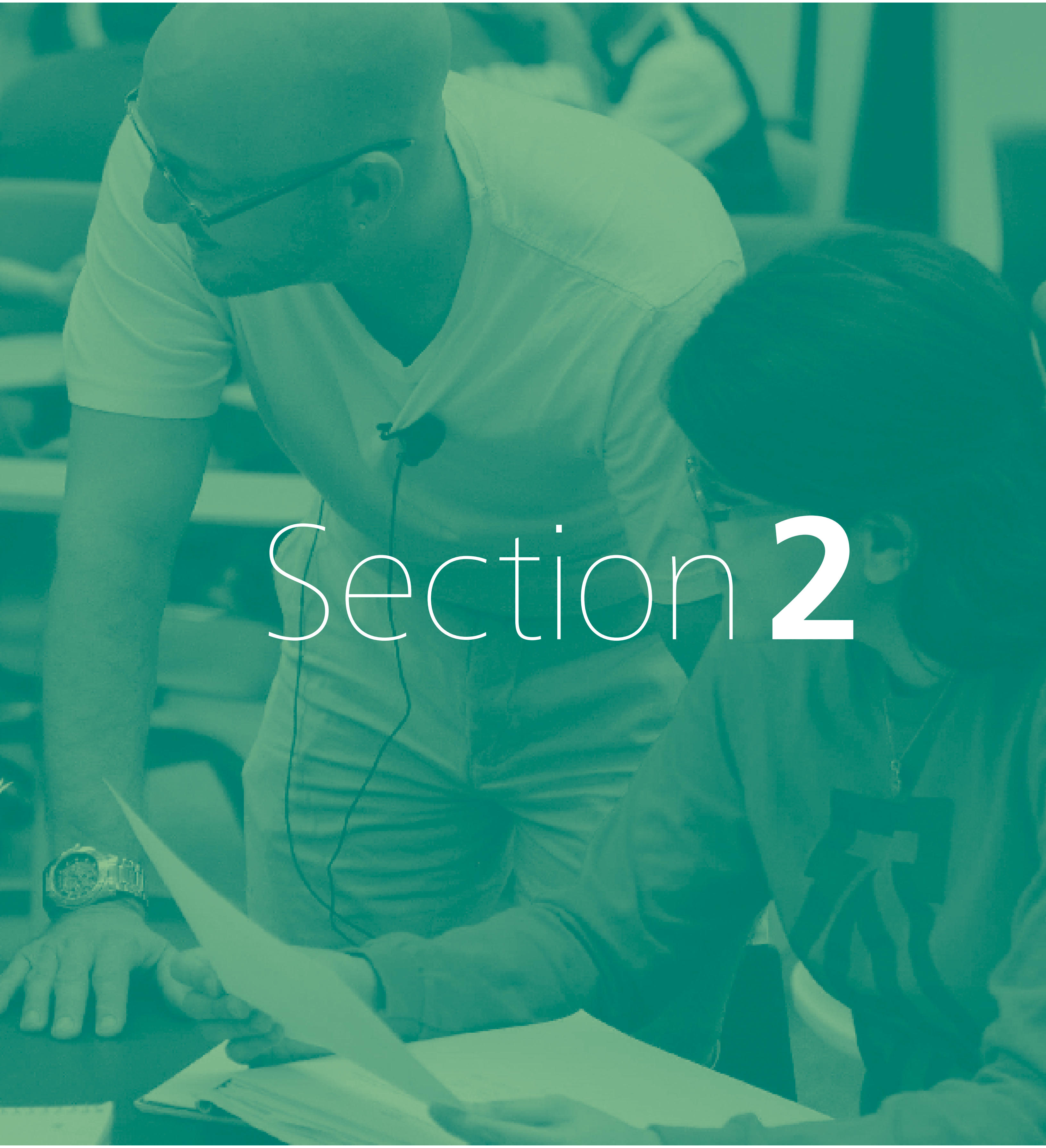

Section 2

PROJECT SITE UNIVERSITIES

The University of Arizona

Brown

UC Davis University of California

University of Colorado Boulder

Michigan State University

The University of North Carolina at Chapel Hill

Penn

Washington University in St. Louis

EXCELLENCE IN TEACHING

To be as excellent in teaching as we are in research.

EVIDENCE

All project sites have peer-reviewed scholarship providing local evidence of student learning.

BY THE NUMBERS

3
Academic Years

39
Participating Departments

162
Transformed Courses

138,531
Total Student Seats in Transformed Courses

AAU STEM Project Sites

Introduction

This section presents summaries and analyses of the strategies and approaches that the AAU STEM project sites are implementing to improve undergraduate STEM education at their institutions.

This section describes the discipline and curriculum reform focus as well as the organizational change models for each of the eight project sites. Looking across the various approaches enacted at the eight project sites and their corresponding outcomes, AAU has identified several cross-cutting strategies that can be implemented to achieve systemic improvements in undergraduate STEM teaching and learning. These cross-cutting strategies are presented in a way that aligns them to the Framework along with evidence to support their effectiveness. Throughout the section also are examples and vignettes highlighting specific ways in which units are successfully implementing long-lasting changes in STEM teaching and learning within their institutional contexts.

Information from site visits, common data collection, and project site reports are among the sources used to provide much of the detailed analysis and identification of cross-cutting strategies.

Change Models

AAU STEM Project Sites: Change Models and Strategies

AAU STEM project sites focused from the beginning on the roles of the academic department in reforming undergraduate STEM education in large part because the AAU Framework and the award process on which it was based made clear that the departments are key to effective and sustainable reform in introductory STEM courses. This approach is contrasted with the all-too-familiar approach of working with a self-selected group of reformers which often had little effect on colleagues and rarely led to institutionalized reform. The central tenet of the AAU Framework is that the key to long-lasting improvement in undergraduate education lies in the acceptance of and support for evidenced-based teaching *by the individuals who teach these courses* and by the *senior tenure-track faculty members and department chairs* who have substantial say in faculty work allocation, in how courses are taught, and in faculty rewards. The AAU Framework also required senior administrators to pledge additional support (e.g., resources, public expressions of support) beyond the project work plan and budget to provide political support for the departments attempting to challenge the way that research universities—and AAU institutions in particular—conduct and value undergraduate teaching.

Before examining the project course and curricular change strategies and the roles of the departments, it is worth noting the importance of project leadership in understanding the nature of the various departmental cultures. These range from a senior-faculty member power structure, to power being vested in department chairs and deans, to more top-down models with the Provost as a driving force. Leadership of project sites designed strategies to fit with local cultures when such a fit was key to successful implementation or to challenge the local culture when it stood in the way of reforming undergraduate STEM education.

Also of note is the importance over time of promoting and developing a larger network of AAU institutions sharing information about undergraduate STEM educational reforms on their campuses. It is in part because of this new norm of sharing information across peer AAU institutions that some project sites were able to successfully reinforce calls for reform by pointing to peer departments at other institutions.

The change models can be categorized into various implicit or explicit models of change based on their emphasis on top-down (central administration), bottom-up (faculty), or a hybrid (e.g., departmental leadership, faculty learning communities) approaches.

Brown University (Brown)

The Brown University AAU Undergraduate STEM Education Initiative project supports the introduction of evidence-based, high impact practices in key introductory courses in physics, chemistry, applied mathematics, and engineering through the implementation of intensive, small group collaborative problem-solving sessions. In these sessions, students work with peers to solve conceptually relevant, context rich problems that expose them to interdisciplinary thinking and learning. The sessions are facilitated by one to three individuals involved in the course, such as primary course instructors, department faculty, postdoctoral researchers, graduate students, and undergraduate students who have previously taken the course. All facilitators receive training prior to the first problem-solving session to learn effective ways to support student teams. Furthermore, regular meetings of course instructors, their department chairs, and Brown AAU Project Team members to discuss successes and challenges of the ongoing course implementations have created a best-practices pipeline to quickly disseminate successes and solutions between project courses. These meetings also enable cross-disciplinary discourse, nurture departmental communities, and engage faculty and graduate students in campus-wide implementation of evidence-based practices.

Michigan State University (MSU)

The main goal of the Michigan State University AAU STEM Education Initiative project is to bring about change in instructional practices and assessments in large gateway courses in order to positively affect student learning. At the onset of the project, faculty from biology, chemistry and physics were brought together to think about three-dimensional learning, which focuses on the core ideas in each discipline, the crosscutting concepts that span science disciplines, and the scientific practices that facilitate students' use of their knowledge. These departmental and interdisciplinary conversations engaged faculty in developing new assessments, instructional activities, and tools to examine the extent to which classroom instruction and course assessments align with three-dimensional learning. A new research instrument was created by the MSU team to characterize assessments in this manner—the Three-Dimensional Learning Assessment Protocol (3D-LAP), and a second protocol to characterize instruction – the Three-Dimensional Learning Observation Protocol (3D-LOP) – is in progress. Furthermore, a competitive two-year fellowship program has

CHANGE MODEL

Unlike most of its AAU peers, Brown is primarily a university-college institution, with a college existing within the context of a research university. The AAU project has stimulated a more critical view of undergraduate STEM courses and the role of the faculty in student success. As a result of the Initiative, many faculty now view themselves as having a key role in whether or not students decide to enroll and/or remain in STEM majors.

The initial change model at Brown relied on the Sheridan Center for Teaching and Learning, which has a distinguished record in promoting the use of evidence-based teaching, to lead the project with departmental involvement limited to some key individuals in those departments. The unexpected departure of the Director of the Sheridan Center required Brown to change both the structure of the AAU project and in its implicit change model. The department chairs and key faculty members filled the vacuum left by the Director's departure and assumed direct responsibility for the AAU project. Brown has created a permanent Faculty Learning Community (FLC) based in departments and colleges to promote best instructional practices in STEM across the campus. The evidence of increased departmental engagement includes several departments (Applied Mathematics, Chemistry, Physics, and the School of Engineering) now leading collaboration with the new Brown Science Center (rather than relying on the Sheridan Center to make the connection). Other evidence of departmental increased engagement includes the chairs (and the Dean of Engineering)—not individual faculty members—submitting proposals to the AAU project leadership (and to the Provost) for AAU-related work.

been established that supports an interdisciplinary community of faculty who are committed to continually improving educational practices in STEM gateway courses by developing new and refined activities, materials, and assessments that align with three-dimensional learning.

The University of Arizona (UA)

The objective of the AAU Undergraduate STEM Education Initiative project at the University of Arizona is to change the culture of faculty instructional approaches to be more student-centered and use active learning pedagogies. The UA project promotes and supports the redesign of introductory STEM courses in three ways: (1) by providing intensive professional development support for faculty to use evidence-based methods; (2) by facilitating faculty learning communities (FLCs) among interested instructors; and (3) by being a driver for change in making more classroom spaces across campus be conducive to active learning techniques. The project team started by developing and institutionalizing FLCs to create a core group of faculty support for reforming teaching in STEM courses. Along with FLCs, the project team created Collaborative Learning Spaces (CLSs) by redesigning existing spaces and teaching student-centered, active learning-based introductory STEM courses in them. The success of the initial results in introductory STEM

MSU has embarked on an extensive institution-wide reform effort in STEM education. Some of these reforms were put in place prior to or co-incident with the AAU project. These actions include hiring highly visible tenure-track professors in DBER and science education (including some endowed chairs), supporting with university funds the CREATE for STEM Institute (CREATE) to coordinate some STEM education activities across campus, and using funds from the Provost to implement a program called the Biology Initiative which focused on improving undergraduate biology education through the investment of new resources in the biology departments and Biological Sciences program. The AAU project at MSU began at the nexus of these activities, which influenced both its model for change, its status at the university, and its strategies. The change model focused first on faculty discussions of core ideas of each discipline, and the ways in which that knowledge is used, rather than on simply changing pedagogical approaches. In this way the intrinsic motivation of faculty is harnessed to bring about change. The hypothesis was that faculty who structure student learning around core ideas and scientific practices would also, by necessity change their instructional practices and assessments. MSU's strategy evolved early on to leverage CREATE in coordinating various STEM reform efforts (CREATE has since expanded to formally include the College of Engineering and Lyman Briggs College in addition to the Colleges of Natural Science and Education) and in supporting various reform efforts both to improve the odds for success in the AAU project and to achieve large-scale impact at the university.

Because the change strategy depends on the restructuring of courses around core ideas and science practices the evidence of change should also incorporate the ways in which both the instruction and assessment of student learning have changed. The AAU project team developed a protocol (the 3-dimensional learning assessment protocol 3D-LAP), that allowed them to gather evidence of the extent of change in course assessments. The 3D-LAP also provides guidance for faculty as they design new assessment items for transformed courses. Another protocol (the three dimensional learning observation protocol 3D-LOP) is under development and will be used to gather evidence for the extent of transformation in the classroom.

As for specific strategies, the MSU central administration invested funds in STEM reform (Biology Initiative) prior to the AAU effort. Because the AAU project was seen as a cornerstone of an overall reform strategy at the university the central administration added support to the AAU team and related work prior to evidence of their effectiveness to assist both the AAU project leadership and CREATE in coordinating reforms across projects and administrative units. Over time the Dean of the College of Natural Science and other relevant campus administrative units supported the coordination of various large-scale STEM reforms under the CREATE umbrella. The success of the AAU project has led directly to a follow on grant from NSF to extend the approach to more courses including upper level courses and to other institutions.

courses resulted in the creation of more CLSs of varying sizes across campus, the development of workshops and instructional guides for faculty on how to best utilize CLSs to facilitate active learning classrooms, and the targeting of FLCs to assist instructors who teach in these spaces. The continual growth of CLSs and faculty members using and interested in using active learning pedagogies in these spaces indicates a cultural shift in teaching is occurring in the desired direction.

University of California, Davis (UC Davis)

The AAU Undergraduate STEM Education Initiative project at the University of California, Davis works to promote an institutional culture that utilizes data and evidence-based pedagogical innovations to make informed educational decisions and continually improve classroom instruction and student outcomes. Through the creation and implementation of a data analytics infrastructure that consists of newly developed tools and visualizations, student data and classroom instructional data are being used to inform and improve instruction, assessments, curricula, student advisement, and student retention. Ongoing course reforms and educational experiments utilizing analytical tools are occurring in introductory biology, chemistry, and mathematics courses, and the development of new data-based educational experiments has spread to other departments. To sustain momentum for these efforts on campus, an annual interdisciplinary Scholarship of Teaching and Learning Conference was founded for instructors engaged in conducting evidence-based educational experiments to share their work. Moreover, the campus project team shares

CHANGE MODEL

The UA change model focused initially on implementing a network of faculty members committed to improving STEM undergraduate education. Labeled the "coalition of the willing," UA used a faculty learning community (FLC) model to enable individuals who were often isolated in their own programs and departments to work collaboratively with like-minded individuals. The FLC provided a mechanism for sharing information about and experiences with evidence-based teaching. The FLC-based model also was able to add members over time thereby increasing the number of faculty members engaged in STEM reform at UA. Since the network was supported by and run out of the Associate Provost's office, this approach combined a type of bottom-up and top-down model for reform. This approach permitted UA to ramp up quickly, using courses taught by members of the FLCs as the initial target. The exception was the existing Chemical Thinking sequence which had been developed prior to the AAU project; it was incorporated into the AAU project in which it has enjoyed a prominent place in STEM campus reforms. The combined bottom-up plus top-down approach shares some characteristics with the change models at CU Boulder (using Departmental Action Teams as an approximate equivalent to FLCs) as well as UNC-Chapel Hill (with a mentor-apprentice model as the bottom-up component of the model).

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The limitation of the "coalition of the willing" model is that courses targeted for reform were not necessarily selected because they were linchpin courses or because they taught the most students. They were selected because members of the FLCs taught them. Again, this approach was consistent with rapid implementation and high commitment by participating faculty to evidence-based teaching. The challenge going forward is that some of the crucial linchpin courses are not taught by members of the FLCs nor are they all controlled by departments with a substantial commitment to reforms.

Despite this limitation, the evidence of successful implementation of course reforms is substantial. Chemical Thinking has been fully implemented. Chemical & Environmental Engineering has redesigned introductory courses. Molecular and Cellular Biology has agreed on a common text and examination. It has fully implemented a reformed introductory course. The Physics department agreed on a set of learning tasks for revising its introductory course. The current number of reformed courses exceeded that which was initially proposed.

The top-down role of the Associate Provost, who is the Principal Investigator for this AAU project site, links the AAU project with institutional resources and political support. Importantly, this office also controls the use of recently redesigned active-learning oriented classrooms. This control ensures that the reformatted classrooms are only used by faculty members incorporating evidence-based instruction in their courses.

The FLC model has been effective in providing a formal mechanism around which reform-oriented faculty members can coalesce. FLCs have gained stature in part because of a deliberate strategy to include a substantial number of tenure-track faculty as participants. In addition, evidence of effectiveness in student learning outcomes, especially course performance in classes taken after the introductory course, was leveraged by the campus project team to gain support by departments for the reforms.

the analytical tools and visualizations they have developed with other interested universities. This collaboration helps to refine existing tools and contributes to the creation of new tools and evidence-based approaches for improving instruction and student outcomes.

University of Colorado Boulder (CU Boulder)

The AAU Undergraduate STEM Education Initiative project at University of Colorado Boulder targets changes in both culture and structures to foster coherent, long-lasting reforms. The project uses a three-layer approach that focuses on faculty practices, departmental culture, and administrative support/policies. Activities in the multilayers include: (1) working with groups of faculty (and often students and staff) in Departmental Action Teams (DATs) to create sustainable mechanisms to address educational issues within departments; (2) applying targeted approaches to individual departments to stimulate cultural change; and (3) working with senior administration and the faculty senate to promote the use of evidence-based teaching practices through incentives and the adoption of a framework for teaching excellence. The three layers are supported by the Office of Institutional Technology and the Office of Institutional Research, which provide a common infrastructure across

CHANGE MODEL

Over time, UC Davis shifted from a top-down change model with student outcomes data seen as the impetus for reform to a more active strategy with project leaders actively participating in the change process. One part of this new strategy was the consolidation of several activities into a new Center for Educational Effectiveness (CEE), which now combines the collection of data about teaching reforms with an administrative and policy effort to encourage adoption of new teaching approaches. The data collection supported by the CEE continues to focus on institution wide and widely disseminated instruments—e.g., ribbon charts on student progress—which enables leaders at the departmental, college, and university levels to follow changes in student progress and learning. In addition, the CEE increasingly is sponsoring the collection of more complex data about student learning outcomes (e.g., higher order thinking skills) whose focus is more on instructors and their academic programs. These additional data are in part an effort to merge bottom-up, faculty-led reforms with university-level information about student trends.

UC Davis does an excellent job of tracking the resources that support each of its key activities. The campus project team pools resources to meet project (and CEE) goals rather than assigning distinct funding sources to unique project activities. The AAU project from the beginning has targeted linchpin courses for reform—those with the largest enrollments and greatest number of majors dependent on them (e.g., General Chemistry). UC Davis has spent considerable time in exporting its data tools to other universities—more than 100 other institutions current use either the ribbon chart or Generalized Observation and Reflection Protocol (GORP) tool.

departments for the use of student data and for the collection and use of observational data on classroom practices. The project, now branded as the STEM Institutional Transformation Action Research (SITAR) project, is housed in the Center for STEM Learning and will continue to support educational improvements and cultural shifts on campus.

University of North Carolina at Chapel Hill (UNC-Chapel Hill)

The objective of the AAU Undergraduate STEM Education Initiative project on the campus of the University of North Carolina at Chapel Hill is to support the widespread adoption of high-structure, active-learning (HSAL) practices in large introductory-level lecture-based STEM courses. The project focuses on increasing the number of redesigned, HSAL-based gateway courses in biology, chemistry, physics-astronomy and mathematics through the implementation

CHANGE MODEL

CU Boulder's change model is unique among the AAU project sites. From the beginning, CU Boulder focused on institutional and cultural change as a method for improving undergraduate STEM education. Change was driven by aligning appeals for action from the administration (top-down) with on-the-ground faculty work via Department Action Teams (DATs; bottom-up) and was supported by infrastructural improvements in classroom data collection and student data visualization. This approach relied on extensive previous classroom and curricular reforms in STEM at CU Boulder through the Science Education Initiative, so it did not include a component that engaged faculty members in reformed teaching. This approach appeared to lag in its effectiveness through the second year of implementation. By the third year, however, evidence suggests that the DATs are taking hold and beginning to provide a bottom-up faculty-led effort to contribute to the push for reform from the central administration.

A DAT is a departmental-based working group of about 4 to 8 faculty, staff, and/or students that works on a cross-cutting educational issue over one or two years, with the support of outside facilitators and the sanction of the department chair. DAT participants choose their focus by developing a vision for undergraduate education in their department; example foci from DATs at CU Boulder include curricular/instructional revision and alignment, improving equity and diversity, and enhancing community among faculty, students, and staff. DATs both implement change and focus on creating lasting structures (e.g., committees, positions, policies) that can continue their work over time (rather than viewing change as a one-time "fix"). DATs maintain transparency by sharing information with and making recommendations for change to the chair, appropriate departmental committees, and the department as a whole. Initial DATs at CU Boulder initiated a variety of structural changes within their departments, including the allocation of several instructor course equivalents to serve as curriculum coordinators; the formation of a standing committee focused on student diversity, retention, and recruitment; and the restructuring of a course sequence to better support majors transitioning to upper division.

CHANGE MODEL

The mentor-apprentice model, the core of UNC-Chapel Hill's STEM reform efforts, has been widely accepted at UNC-Chapel Hill since the start of the AAU project because of its demonstrated success in improving student learning outcomes, the intentional inclusion by project staff of senior tenure-track faculty members in the *apprenticeship* role (with the mentor being an individual well-schooled in the use of evidence based instruction), and the relatively low barrier to implementation because of its low cost. Including top researchers in an instructional reform role has been essential to gaining widespread support for reforms by departments and the central administration. Unlike UA, UNC-Chapel Hill uses FLCs for each participating department which in theory is meant to increase the odds of a department adopting STEM reforms.

Like UA, UNC-Chapel Hill has used data on student success in reformed courses to generate political support for institutionalizing the reformed courses. This approach has meant using widely accepted metrics when available such as concept inventories in Physics. The goal here is to use data on student outcomes for both instructors *and* for the wider departmental audience. As with UA, collecting data relevant to departmental success is crucial. For UNC-Chapel Hill that has meant reducing the number of failing grades and withdrawal rates from STEM as much as it has meant demonstrating improved student learning outcomes. It has also helped the institution demonstrate that reformed courses are substantially reducing the classroom performance gap between majority and underrepresented-minority students.

of a mentor/apprentice program that facilitates the transfer of HSAL teaching techniques across instructors. In the mentor/apprentice program, faculty who are experienced in HSAL practices (mentors), and faculty who have less experience in HSAL methods (apprentices) work together in pairs to teach courses that have been redesigned. After completing the co-teaching experience, apprentices go on to teach reformed courses that utilize HSAL practices on their own. Cohorts of current and past mentors and apprentices also meet on a regular basis to participate in department-based faculty learning communities. Thus, the project works to create support and incentives, and reduce barriers to the adoption of undergraduate STEM teaching methods that have been demonstrated to improve student learning gains and close achievement gaps.

University of Pennsylvania (UPenn)

The project team at the University of Pennsylvania aims to improve introductory courses in mathematics, chemistry, physics, and bioengineering through utilizing teaching practices that foster active learning and student engagement. In 2013, the university launched the Structured, Active, In-class, Learning (SAIL) program. The program, facilitated by the university's Center for Teaching and Learning, assists instructors as they develop, implement and evaluate active learning activities to transform their classes into SAIL courses. SAIL courses provide students with the opportunity to struggle through the application of course content—often the most difficult part of learning for students—with guidance from instructors and help from their peers. Thus, SAIL courses require students to do work outside of class time to prepare for in-class activities. The Center for Teaching and Learning works to disseminate SAIL practices across campus through monthly seminars, provides support for the creation of educational videos that can be utilized by students outside of class time, provides training for SAIL course Graduate Teaching Assistants, assists in the development of more active learning classroom spaces, and provides financial support for faculty reforming their courses through small grants. Assessments and the creation of new classrooms have also been an important part of UPenn's change model. The new classrooms create a physical incentive for faculty members to assess their own class and rethink teaching.

Washington University in St. Louis (WashU)

The project team at Washington University at St. Louis, with support from The Teaching Center and the Center for Integrative Research on Cognition, Learning, and Education (CIRCLE) promotes the widespread use of multiple active-learning

CHANGE MODEL

UPenn is likely the most faculty-centric institution among the AAU projects. The power for change is invested primarily in the collection of individual faculty members at this type of institution with the role of the central administration seen primarily in terms of resource allocation and political support. In this model the unit of change is the individual faculty member in her or his classroom. Although many individual faculty members are involved in UPenn's AAU project, representing six departments, project leadership is primarily invested in the Center for Teaching and Learning (CTL). Unlike WashU's CIRCLE or MSU's CREATE for STEM, the key personnel in UPenn's Center are not tenure-track faculty members. The tradeoff for this arrangement is as follows: CTL does not have the same prestige or clout as department-led reform initiatives but this arrangement is consistent with forming a network of individual faculty reformers when no departmental unit has sufficient numbers to form its own collective. To date UPenn has instructors participating from Bioengineering, Biology, Chemistry, Earth and Environmental Science, Mathematics, Mechanical Engineering, and Physics. Overall this approach seems consistent with effective implementation of course reforms and dissemination; less clear is the long-term support of academic departments and central administration, although the resources pledged by central administration to promote STEM reforms to date is an encouraging sign.

The primary mechanism for reform is the SAIL format used as a rubric for course reform across departments. The CTL helped establish and coordinate a STEM Faculty Advisory Board which serves to coalesce interest in these reforms across individual faculty members. CTL also serves to foster a network for STEM reform by providing Teacher Assistant training across programs and departments.

strategies in lower-level STEM courses by scaffolding faculty professional development and by creating an environment in which teaching is a community effort. The project builds a support structure and collaborative teaching culture in which introductory STEM faculty can develop, try out, evaluate, reflect on, and refine new active-learning-based teaching methods. Faculty members are supported through many opportunities including summer institutes, learning communities, reading and discussion groups, a faculty fellowship program, a junior faculty mentoring program, and individual instructional consultations. Additionally, evaluation studies of pedagogical practices and professional development programs are conducted that create feedback loops to faculty members about their active-learning implementations, and to CIRCLE about their programs. These evaluation studies also enable the project team to improve innovations, foster a wider adoption of active-learning strategies, and contribute to current knowledge about the impact of evidence-based methods on student learning and effective teaching. ■

CHANGE MODEL

Although on paper the WashU AAU project looks similar to that for UPenn, the structures and strategies for reform are quite distinct. The Center for Integrative Research on Cognition, Learning, and Education (CIRCLE) includes tenure-track faculty (like CREATE for STEM at MSU), in addition to permanent research scientists, and has more official presence with departmental faculty and chairs than CTL at UPenn. As one consequence, WashU from the beginning has been able to focus on curriculum and scaffolding rather than individual course reforms as well as target sustainability and cultural form. CIRCLE reports to the Provost and is funded by hard money from the Provost and Chancellor.

CIRCLE and the Teaching Center coordinate the Faculty Fellows program and FLCs. It monitors STEM teaching across campus (not just AAU reforms). As such it is similar in function to CREATE for STEM at MSU (though with a different reporting structure) and the CEE at UC Davis. CIRCLE enjoys the support of key departmental leaders which allows CIRCLE to operate in more of a partner role with academic units than as a support structure (more typical of traditional professional development centers). Like most AAU project sites, WashU has targeted linchpin introductory STEM courses for its reform efforts (i.e., Chemistry, Biology, Physics). As a result of the AAU project at WashU, institutional funding has been secured to target two science departments for reform efforts going forward (Biology and Psychology/Brain Science).

Common Data from Project Sites

To document cross-institutional effects, AAU collected data from all project sites over a three-and-a-half-year period. Common data collection included a survey of instructors in participating departments; department chair narratives on policy and practice to assess teaching in the promotion and tenure process; and campus and department level assessments of learning spaces.

The instructor survey [see Online Appendix for project site common data collection materials] focused on:

- Classroom practices: Instructors were asked to rate how descriptive various statements were of their own teaching practices.
- Attitudes towards teaching: Instructors were asked to indicate their level of agreement with statements about teaching practices and techniques.
- Professional development related to teaching: Instructors were asked to rate the availability of, and their participation in, various types of on- and off-campus professional development activities.
- Institutional environment for teaching: Instructors were asked to indicate their level of agreement with statements about the attitudes of other instructors, department chairs, and campus administrators toward teaching, as well as their perception of how important a role teaching played in annual and salary reviews and promotion and tenure.

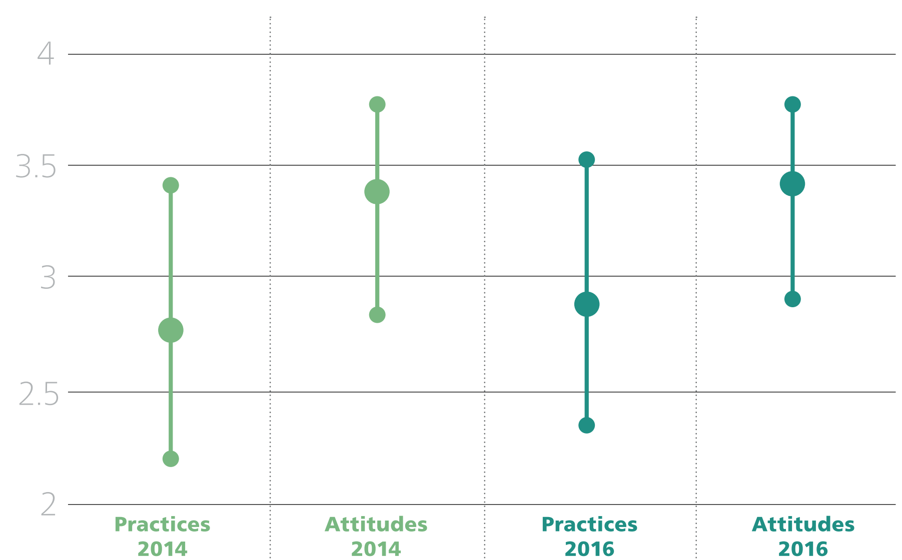
The survey was administered twice, in 2014 and 2016, to all instructors in all participating departments at the eight project sites. Respondent numbers and populations varied between the two survey administrations, but in both cases more than 60% of respondents were tenured or tenure-track faculty, and more than 50% of respondents taught lower-division courses.

The figure below shows the average response to each survey question about practices and attitudes in each survey administration (on a 1 to 4 scale from "strongly disagree" to "strongly agree"). Focusing on practices, the range of average responses moved from 2.20–3.40 to 2.34–3.51, and overall mean response moved from 2.76 to 2.89. While the differences are not statistically significant, none of the items received a lower score in 2016 than in 2014; one stayed the same, and 11 of the 12 moved higher.

Focusing on attitudes, the range of responses moved from 2.83–3.76 to 2.91–3.75, and overall mean response moved from 3.37 to 3.42. Again, the differences are not statistically significant, and most of the shifts are very small, but 17 of the 19 items moved upward (one remained the same and one shifted downward very slightly). Interestingly, the biggest change in attitudes was manifest in the item about inclusivity, a sign that instructors have come more conscious of such issues.

After the first administration of the survey, we identified a gap between attitudes and practices: that is, responses to attitudes questions were more positive than those about practices that would support such attitudes. The gap narrowed slightly in the second survey administration, mostly due to changes in practice, but it still exists, suggesting there is more work to be done. Also, within the overall sample, there may be important differences between institutions, disciplines, and instructor roles on campus (e.g., tenured faculty versus lecturers or graduate student instructors) worth additional investigation.

Levels of agreement (maximum, minimum, and average) with statement about teaching practices and attitudes.



Pedagogy

Extent of Participation

Direct participation of departments, courses, and students (in terms of student-seats) in the AAU Initiative grew at the eight project sites over the three years of the project. At the same time, AAU encouraged other non-AAU project site institutions and departments to undertake reforms.

At the project sites, the total number of participating departments increased from 28 (Year 1) to 37 (Year 2) to 39 (Year 3). The total number of courses involved increased from 69 (Year 1) to 143 (Year 2) to 162 (Year 3). The total number of student-seats increased from around 38,000 (Year 1) to 45,000 (Year 2) to nearly 56,000 (Year 3). These numbers are continuing to rise because the reforms are expanding to more sections and additional courses.

The table below depicts the number of faculty members by type of appointment engaged in course reforms.

Faculty Participation

FACULTY	TENURED	TENURE TRACK	NOT TENURE TRACK	INSTRUCTORS	TOTAL
Year 1	48	9	19	31	107
Year 2	89	22	43	36	190
Year 3	99	27	53	51	230

It is important to note that each project site institution had its own plan for the project, and those who included more departments and courses are not necessarily "better" than those which included less. However, the primary goal of the Initiative is to spread evidence-based pedagogical practices as widely as possible.

Implementation

All project sites showed evidence of dissemination beyond the initial target courses and faculty members. All eight project sites increased the number of courses targeted for reform based on evidence-based pedagogy (some expanded the number of sections of the same course) and all increased the number of faculty members (tenure-track and non-tenure track) participating. One-half of project sites expanded their reach to additional departments. One-half of project sites developed and disseminated common tools used to assess teaching and instruction, in some cases adopted by the university as a whole. Several project sites linked co-curriculuar activities with reformed courses to increase retention in STEM majors.

At Brown, innovative pedagogy formats used during the three years of the project have now became the departmental norm for 13 courses. Instructors of some of the introductory physics classes are committed not only to innovative pedagogy, but also to assessing students' learning gains every semester and building a longitudinal understanding of how the outcomes of their instruction are evolving with time. Also, the number of academic units involved has grown. In the Fall 2013 semester, only the departments of Chemistry and Physics were involved in the AAU STEM project. Now, the Division of Applied Mathematics, the School of Engineering, and the Division of Biology and Medicine and their respective staffs are engaged in offering innovative pedagogy to their students in introductory and mid-level undergraduate courses.

One of the key findings from the work undertaken at CU Boulder was the need to shift from individual faculty and administrator consultations to departmental working groups. CU Boulder developed a new model for this work, called a Departmental Action Team (DAT).[66] In the DATs departmental members work collectively, addressing unit-defined issues meant to improve undergraduate education in a sustainable manner. The project has facilitated a total of six DATs to date, which have often dealt with priority needs specific to each department. Examples include creating curriculum coordinator positions to better link sequences of courses, addressing diversity issues, and improving use of data in assessments.

One measure of success of the DAT approach is the expansion from the original departments—Interactive Physiology and Physics—to include Ecological and Evolutionary Biology, Mathematics, Electrical and Computer Engineering, and Information Science. There is now more interest by departments in forming a DAT than there are resources to support that effort. CU Boulder sought and was awarded NSF IUSE funds to support the expansion of DATs, both locally and at a second partner campus (Colorado State University). DATs will expand into Geological Sciences, Atmospheric and Oceanic Sciences, and Computer Science at CU Boulder in the fall of 2017.

66 CU Boulder Departmental Action Teams (DATs)

WashU's efforts have expanded far beyond the original scope of the project, including into non-introductory and non-STEM courses. Work has continued into a fourth year, with 14 departments/programs, 71 course sections, and 50 faculty implementing active learning. All courses that adopted active-learning continued to implement it in later semesters, which provides evidence of sustainability. Additionally, one faculty member in the School of Law has expressed interest in the clicker program, which, if implemented in their course, would expand these efforts to a new school and to graduate-level students.

The UPenn's SAIL program continues to grow. In departments where individual instructors, rather than the department, choose to teach SAIL courses, all instructors plan to continue offering their courses in the SAIL format. The Office of the Provost, through the Center for Teaching and Learning, has sent out the call for more SAIL course development grant proposals, and the number of SAIL courses is expected to continue to grow over the next academic year. Some departments have expanded their efforts beyond introductory sequences to include upper level courses.

Efforts have also expanded to additional STEM departments and some non-STEM departments. For example, the SAIL version of one of the introductory economics courses, reaching approximately 600 students annually, is now in its fifth semester, and has featured iterative improvements based on student feedback and learning outcomes. This course offers the opportunity to explore ways to scale this approach for larger classes, and the number of students allows for the evaluation of specific course elements.

Beyond SAIL, there has been an increase in other active learning efforts. One such mechanism is the design of active, student-centered recitations to complement larger lecture courses. The Math, Chemistry, and Psychology Departments launched versions of their introductory courses with active recitations this year. Lessons from the SAIL initiative have been helpful in other endeavors, as instructors can use previous student feedback on activities and group work to shape their approach.

At UNC-Chapel Hill, a noticeable change has occurred in the culture of the departments involved in the AAU project. There is also evidence of spill-over effects to other departments. There have been additional course redesign efforts in Chemistry and Biology. The Department of Mathematics hired a lecturer knowledgeable in evidence-based methods and has begun to redesign its calculus sequence. The Department of Anthropology initiated a department-wide course redesign effort that was influenced by the AAU project, and the Departments of Economics and Psychology have continued to expand their use of evidence-based teaching methods during the AAU project. Other faculty members within the participating units have begun to incorporate many of the ideas that have developed from the project. At least one example of a mentoring relationship was established with a faculty member at another university.

CASE STUDY

Structured Active In-class Learning

Many of the University of Pennsylvania's activities within the AAU Initiative fall under the umbrella of Structured Active In-class Learning (SAIL). Broadly speaking, the goal of SAIL classes is actively involving students in doing science and mathematics, rather than watching someone else do it or listening to them talk about it. All SAIL classes include three elements: 1) establishing learning goals, 2) in-class active engagement, and 3) use of out-of-class time (including watching on-line modules that contain short videos of lectures and demonstrations and tackling practice problems before they even arrive in class).

The university's Center for Teaching and Learning serves as a central resource for faculty who teach SAIL classes or are interested in doing so. The Center provides both consultations and a formal program of support for faculty and TAs interested in this teaching, including a SAIL Seminar for faculty and SAIL TA Training. The Center also helps coordinate instructor access to active learning classrooms on campus.

In addition, along with the Vice Provost for Education, the Center invites faculty to submit proposals for course development grants to support the creation of SAIL classes. SAIL grants provide faculty with $5,000 for their preparation time or for graduate student assistance in the process of developing in-class exercises, any out-of-class materials, or assignments and assessments. As of the 2016-2017 year, there have been 13 SAIL grants in 11 different fields.

The number of SAIL courses continues to grow. In 2016-17, the university had 27 SAIL courses, including eight in non-STEM fields. This is an increase from nine total courses in 2013-14. Likewise, the number of instructors who teach SAIL courses increased from 12 to 33 during the same interval. Overall, 51 unique instructors at UPenn taught or will teach SAIL courses between 2014 and the summer of 2017, and numbers of both courses and instructors are expected to continue to grow.

UC Davis has expanded its efforts in several departments. Introductory biology underwent a major and long-lasting change as a result of a combined Gates Foundation and AAU effort to improve student outcomes. Teaching assistant training resulted in a highly structured discussion environment that emphasized group work and high order cognitive skills development. Combined with a modeling-focused active lecture, students are now able to successfully complete substantially higher order problems, as based on Bloom's taxonomy. In addition, the changes in the introductory course are having measurable effects on subsequent course performance.

In the Chemistry Department the introductory chemistry restructuring project expanded substantially beyond the rethinking of the initial course sequence. Three major components emerged including: 1) the methodical measurement of learning as a function of the instructional approach for the introductory courses, 2) a major overhaul of the chemistry preparation pathways, and 3) an entirely new three quarter sequence for life science majors.

For the first component, it was shown that instructional approach could be reliably measured using the Classroom Observation Protocol for Undergraduate STEM (COPUS) instrument via the Generalized Observation and Reflection Platform (GORP) tool, which was developed by the CEE team.[67] Additionally, it was found that active learning instructional approaches yielded improved learning compared to traditional approaches, especially with less prepared student populations.

For the second component, the Assessment and Learning in Knowledge Spaces (ALEKS) preparatory chemistry adaptive learning summer self-paced course was tested, replicated, and fully incorporated to help prepare students for immediate entry into the chemistry sequence. In summer 2016, over 600 students could enter the chemistry sequence without needing a three-unit, non-credit bearing, preparatory course in their first quarter. This approach better prepares students, saves them time and money, and improves initial chemistry course success. The overall success of this program has inspired the Math Department to try a similar approach.

For the third component, this approach focused on conceptual knowledge and life science application with an entirely revised laboratory that emphasizes open-ended problems. The Chemistry Department chose to adapt the UA Chemical Thinking curriculum for several of the courses and currently is examining the impact.

MSU's AAU project focused primarily on the main lecture sequences in general chemistry, introductory biology, and introductory physics. However, other course committees and instructors have begun to use the three dimensions developed by MSU (scientific practices, crosscutting concepts, and core ideas) and adaptations of the three dimensions as the framework for transformation efforts. These courses include a pre-general chemistry course that focuses on connections between chemistry and mathematics, organic chemistry, the general chemistry laboratory sequence, one section of an upper-division physical chemistry course, second-tier yet foundational biology courses including ecology and evolution, calculus for life science students, and introductory physics for life science students.

The goals of MSU's Biology Initiative and its AAU project overlapped substantially, including an overall focus on scientific practices and core ideas in courses and degree programs. Additional TAs and LAs provide the resources

67 UC Davis Center for Educational Effectiveness Analytics

necessary to facilitate more student-centered and active approaches in class meetings as well as implement more frequent assessments and feedback. Curriculum coordinator positions have also been implemented for several courses, to develop and maintain a shared vision for the courses based on a core set of learning goals and to develop and evaluate new course materials and to coordinate assessment of student learning across sections.

In the Chemistry Department, implementation of transformed courses led to a permanent increase of resources including the creation of two new permanent instructional faculty positions: a lecturer for general chemistry and a Director of General Chemistry Laboratories. These positions allowed the Director of General Chemistry to focus on the transformation effort, coordinate the new materials, and provide support for faculty who rotate into the new course.

The success of the transformed course in physics has led to faculty support for expanding the course to additional sections, piloting a second-semester course, developing an integrated lecture-lab model for those students having to take both, and further development of the transformed laboratory. The Physics faculty voted overwhelmingly to embrace these changes to the extent that the physics budget can support them. The department has committed to supporting a single instructor line that is devoted the expansion and continued development of the transformed course, and additional resources for development of both transformed lecture and laboratories have been endorsed by the faculty and requested from the college and Provost.

All of the UA's originally proposed course reforms were expanded within target departments. Additionally, in chemistry, the work on Chemical Thinking has expanded to:

- The development of a version of the curriculum for Honors students.
- The creation of a pilot preparatory course to better support students with weak academic backgrounds before they enroll in Chemical Thinking.
- One faculty member in Organic Chemistry using active learning instructional approaches and teaching in one of the Collaborative Learning Spaces.
- The use of the Chemical Thinking Curriculum at other three other U.S. universities.

In physics, seven different instructors have used active learning to teach one introductory class. The active learning, student-centered teaching approach has been taken in five other physics courses, with reform of a sixth beginning this fall. The department has also started its own Faculty Learning Community focused on improving instruction and student learning in undergraduate physics courses.

Evidence Related to Student Learning

Each project site included a plan for assessing the effectiveness of the classroom interventions they proposed to use or test. These varied in form from site to site. AAU encouraged individual sites to use these data to inform ongoing practice, and to publish results as appropriate. AAU did not ask the sites to report learning outcomes data in a form that could be aggregated as with the responses to AAU's instructional survey. Summarized here are results shared in the sites' annual reports that point to trends across the Initiative toward improved learning gains, decreased failure rates, improved persistence from introductory to later courses, and shrinking achievement gaps for previously underserved students.

Across the project sites a variety of tools were used to measure content or skill mastery. These included validated concept inventories developed by academic disciplines, inventories developed locally, new assessments developed following departmental adoption of learning goals, common exams administered across multiple sections of a course, and course grades. In addition to measures of content and skill mastery, most sites tracked additional student outcomes indicative of improved instruction often in line with institutional priorities.

Although many of the interventions are still in process with data gathering and analysis at an early stage, some initial (and substantial) trends are evident. Every site reported some improvement in student learning outcomes. The magnitude and significance varied according to the different stages of the reform process across the institutions and across departments in some institutions. Dramatic reductions in achievement gaps especially for women, under-represented minorities, and first-generation students were observed in some sites. Reports of decreased DFW (D grades, F grades, and withdrawals from a course) rates were common, as were increased persistence to the next or later courses and success in later courses as measured by grade performance. Improved performance on exams sponsored by disciplinary societies was observed, as was stronger performance on disciplinary concept inventories. Some sites also have tracked the effects of instructional interventions on more general psychological factors, such as self-efficacy, metacognition, and student attitudes toward science.

Project site outcomes documented in 42 peer reviewed articles.

MSU included an explicit strategy for changing the ways that student learning is assessed. Use of the 3D-LAP allowed the project team to explicitly identify assessment tasks that require students to use their knowledge in the context of scientific practices.[68] Early research results from MSU's work are very promising, and provide the team with insights about factors that affect transformation of large scale courses. Research studies on student learning in chemistry show that compared to students in traditional courses, students in the transformed courses show significantly increased understanding and use of core ideas in chemistry. This, coupled with a decrease in the rate of DFW, on average, around 450 more students per year now pass the course with a grade of C or better.

68 James T. Laverty, et al., Characterizing College Science Assessments: The Three-Dimensional Learning Assessment Protocol, *PLOS ONE* 11 (2016): e0162333.

John Pollard, Associate Professor of Practice, teaching a Chemical Thinking course at the University of Arizona.

At UNC-Chapel Hill the academic year average D/F rates in redesigned courses dropped from 11.5% in 2013 prior to the AAU project to 9.5% in 2016. The learning gains in HSAL courses were 13% higher than in traditional courses. Teaching Assistants at UC Davis trained to use active learning practices and adaptive learning technology from Carnegie Mellon were able to raise student outcomes by half a letter grade (and/or increase the probability of passing exams by 66%) in introductory biology.

As a result of the Initiative at WashU, 57 STEM faculty, from 9 of our 11 STEM departments, have taught 49 different courses (76 course sections) using personal response systems (i.e., "clickers"). WashU's evaluation studies found that the clicker-based active learning used in three of the courses, which were high-enrollment introductory science courses, was positively associated with exam performance, even when students' cognitive characteristics (ACT, AP test scores, scores on course pre-tests) and class attendance were accounted for.

CU Boulder's Departmental Action Teams each worked toward department level consensus on learning goals, pedagogical approaches, and assessments aligned with the learning goals as a way to build widespread and lasting change. In the physics department, CU Boulder conducted pre/post conceptual assessments of four courses (Calculus-based General Physics I and II and Algebra-based General Physics I and II) over five semesters of the AAU project. The results averaged across semesters indicated that students from all four courses had higher post-test scores between 25% and 30% in reformed courses.

UA found improved learning gains in sections of physics with calculus taught with active learning approaches, compared to the traditional lectures class. The reformed course final exam scores outperformed the traditional course on every exam item. The redesigned Chemical Thinking has demonstrated that students' performance on the American Chemical Society standardized exam were not significantly different from those in the traditional course. However, students in Chemical Thinking performed significantly better on a conceptual chemistry questionnaire (55.3% vs. 44.3%) and had significantly more positive attitudes toward chemistry than the traditional group.

Not surprisingly, since the Initiative overall intended to catalyze change, much of the assessment work was used formatively over the several years of the interventions. Reports included multiple accounts of fine tuning of approaches based on student outcomes, with significant growth and insights into factors that make a difference in impact such as student readiness and interest, physical settings for instruction, whether students are taking the course for the first time or repeating it, and effective practices for managing group dynamics for group work. UC Davis tested among other things the use of free online textbooks in two disciplines, and found students did as well with them as with traditional textbooks (a significant financial benefit for the students).

The first published reports of specific impacts can be found in the "AAU STEM Scholarship" section on page 102. ■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Course Transformations
Incorporating
Changing
Creating
Informal Learning Exper
Sponsoring
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Workshops
Community outreach
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Scaffolding

Pedagogical Expertise

One strategy to successfully institutionalize reform is to embed instructional expertise within the department to provide educational leadership and to support all faculty members in the adoption and use of evidence-based pedagogy. Although the types of appointments of individuals with this type of expertise vary widely (e.g., tenure-track, non-tenure track, junior and senior ranks), these individuals all have in common an understanding of the discipline and how students learn best within the discipline. When used most effectively, these individuals are well positioned to provide educational leadership to the department.

Individuals in these roles can help redesign courses, co-teach courses with other faculty members, take on the responsibility for departmental-wide educational improvement, and produce scholarship for the broader higher education community based on the evaluation of reformed courses. These individuals often will also engage in efforts with other STEM departments to achieve broader institution-wide systemic STEM teaching reforms. Acceptance and support of individuals with instructional expertise—even those in tenure-track positions—by departmental leaders and by tenure-track faculty members is also an essential element for long-lasting change. In Biological Sciences, Physics and Astronomy, and Chemistry, The UNC-Chapel Hill has made several teaching-related hires with backgrounds in evidenced-based STEM teaching since the start of the AAU project. Over time, these personnel have been seen by chairs and their faculties as strategic hires whose help in achieving overall departmental instructional objectives is paramount. UNC-Chapel Hill staff (and AAU staff) have found these hires fully entrenched within the respective departments and are beginning to have "lasting impact on the teaching culture within departments. As another example, MSU hired a curriculum coordinator for introductory biology courses and added staff to develop inquiry-based laboratories in Chemistry. As a third example, WashU is embedding educational specialists in STEM departments. WashU also hired a coordinator for General Chemistry and appointed a new Vice Dean for Education in the College of Engineering.

CASE STUDY

Mentor-Mentee Approach

The University of North Carolina at Chapel Hill has embedded pedagogical expertise within departments by capitalizing on their faculty track of lecturers. Departments have used these positions to hire individuals who bring educational expertise and leadership into departments. Such lecturers, who are eligible for tenure, have experience in evidence-based teaching methods in the sciences and are evaluated on their ability to contribute to the ongoing evolution of the departmental and institutional teaching culture.

The presence of teaching-oriented faculty who are treated with status equivalent to more research-oriented faculty has lowered the barrier for entry for all faculty in departments to think about how to infuse evidence-based pedagogy into their classes. One way in which this knowledge has been disseminated is through mentor-apprentice relationships between teaching-oriented and other faculty, including senior tenured faculty. Departments have incentivized these relationships by giving both faculty members credit for teaching the course they are working on together that term. So far in the project, 27 such "course releases" have been provided. Going forward, the Dean of the College of Arts and Sciences has committed to supporting four course releases per year for course redesign and apprenticeships for three years.

Michael Crimmins, a senior professor of chemistry, participated first as an apprentice and later as a mentor. Crimmins undertook a complete reform of the Introductory Organic Chemistry 1 course into a high structure, active learning format.

Inside Higher Ed quoted Crimmins: "We're trying to get students to engage with content multiple times, to get some information before they come to the classroom. Then I'm a lot less of a lecturer than I used to be. … The huge change is that I don't walk into class with notes or a PowerPoint -- I have some notes -- but it's not me talking, talking, talking. I talk a little bit but I'm posing students questions, and they're talking among themselves or in groups."

After redesigning the course, Crimmins observed that failure rates had been reduced for all students (from 17% to 6% when comparing the 2002-03 to 2013-14 classes), but notably for African American students (from 33% in 2002-03 to 14% in 2013-14) and all underrepresented minority students (from 21% in 2002-03 to 11% in 2013-14).

Other courses at UNC-Chapel Hill, including in the biology department, witnessed a similar closing of the achievement gap for both first-generation and African American students. Additionally, evidence shows more women are now enrolling in gateway science courses at UNC-Chapel Hill.

Individuals hired to enhance the instructional expertise of their programs and departments—even tenure-track discipline-based educational researchers—can find acceptance by their departmental colleagues difficult. Even though UC Davis is part of the University of California System, which has a designated employment category for teaching-oriented positions endowed with the possibility of tenure (LPSOE - lectures with the potential of security of employment), some of its STEM departments have found it difficult to fully utilize and accept LPSOE hires. Cultural differences between departments make it quite difficult to see uniform change across UC Davis in this respect. The Center for Education Effectiveness (CEE) is working with departments and colleges to clarify promotion and tenure criteria and create tools to help all faculty members including LPSOE hires document their evidence-based practices.

In addition to adding positions with specific teaching expertise, enhancing the value placed on teaching at research universities starts with stated expectations for teaching when new tenure-track faculty members are hired. At UNC-Chapel Hill, for example, new STEM hires (including those with tenure-track positions) must have experience in the use of evidence-based teaching and be prepared to participate in the mentor-apprenticeship model. Also, MSU substantially enhanced the visibility of STEM educational reforms by hiring several tenure-track endowed chairs focused on STEM educational reforms.

Institutional Data Analytics and Visualizations

Data analytics and visualizations played a role in most of the project sites. Data focused on both faculty practices and student outcomes, the latter including academic performance and progress toward the degree. Much data collection and visualization about faculty instructional practices focused on classroom observation protocols.

UC Davis developed the Generalized Observation and Reflection Platform (GORP), which has been used with the Classroom Observation Protocol for Undergraduate STEM (COPUS) protocol to observe interactions between students and faculty in large STEM classrooms.[69] This tool has been disseminated through the Tools for Evidence-Based Action network and is now in use by over 100 universities.[70]

At CU Boulder, classroom observations were conducted with modified versions of the Teaching Dimensions Observation Protocol (TDOP) and COPUS.[71] CU Boulder's classroom observation protocol has been branded as VIP/OPLE (Visualizations in Instructional Practice & Observation Protocol for Learning Environments). The university's Office of Information Technology is working

69 UC Davis GORP Tool and COPUS Protocol
70 Tools for Evidence-Based Action
71 Teaching Dimensions Observation Protocol (TDOP)

CASE STUDY

Departmental Action Teams

To embed pedagogical expertise within departments, the University of Colorado Boulder developed a new type of faculty, staff, and student working group called a Departmental Action Team (DAT). DATs support members of a department in identifying an educational issue of broad-scale importance that they want to address and in making sustainable changes by designing and implementing new structures and by shifting departmental culture to address the issue.

A DAT consists of a self-selected group of about 4-8 participants and an external facilitator; the departmental participants are primarily faculty, but may also include postdoctoral researchers, undergraduate and graduate students, and staff. DAT members select an educational issue of shared interest within their department and work collaboratively to address it. A DAT's focus goes beyond individual course redesign to broader issues. Moreover, the team works collectively, which distinguishes a DAT from a similar structure, the Faculty Learning Community.

DAT facilitators bring expertise in educational research and institutional change, help coordinate logistics, and help the group to work together in a collaborative fashion. Additional incentives (such as service allocation, teaching credit, and other recognition) ensure that participation in the DAT is not a wholly volunteer act, but rather is itself built into the departmental structure and reward system. Thus far, six DATs have been facilitated, pursuing a range of different goals. For example:

- The Mathematics Department's DAT focused on integrating core courses for majors by collecting and analyzing data related to these courses. As the result of this work, the department has developed a new course for majors that it will begin piloting over the coming year. By revisiting student outcome data, the DAT will assess the impact of the course.
- In the Physics Department, the DAT successfully created an ad hoc committee to address issues of diversity. Among other activities, this committee is working to redesign the department website to better serve and recruit underrepresented students, taking steps to encourage faculty mentoring, and creating regular opportunities for members of the department to engage in conversations and self-education around issues of equity and inclusion. The DAT is now a standing committee in the department, using data to guide decision-making, and will continue to collect data about student success (broken out by different demographic groups) to understand the impact of its work.
- The Information Sciences Department was newly formed in fall of 2015. Its DAT worked to develop its undergraduate curriculum and set up basic procedures for operation. Backwards design techniques were used to create the curriculum for this new major, starting with big picture goals and mapping them backwards into specific sequences and courses.

on a scalable version of the TDOP that will provide faculty, on a voluntary basis, with observation-based visualizations of what happens across class periods.[72] This service should benefit faculty members interested in gaining new insights into the patterns of their class activities, documenting changes as they try out new methods of teaching, and finding new ways to communicate about their teaching with colleagues.

WashU is studying faculty use of clickers using both a quantitative observation tool, the Observation Protocol for Active Learning (OPAL), and qualitative interviews. Observational data are analyzed to identify patterns and classify instructors into four categories based on how they used active learning with clickers in their classrooms.[73] OPAL, which was developed as part of the AAU Initiative, has been institutionalized at WashU by the Teaching Center. In addition to the 200+ classroom observations made as a part of AAU research studies, the Teaching Center has integrated data from the tool into faculty consultations. A visual timeline of the data can be generated, providing faculty with an overview of the activities that occurred in their classroom. The timeline data can be used in addition to a more traditional classroom observation by a faculty developer, an approach WashU calls Multimodal Observation for Scholarly Teaching (MOST).[74]

MSU has developed the Three-Dimensional Learning Assessment Protocol (3D-LAP), a set of criteria that can be used to determine if an individual assessment item (or cluster of items) aligns with a scientific practice, crosscutting concept, or disciplinary core idea (the "three dimensions").[75] They have used the 3D-LAP to characterize almost 5,000 assessment items over the course of the AAU project at MSU, fully representing all 200+ course sections of the eight relevant gateway lecture courses in biology, chemistry, and physics.

Institutions have looked at a range of student-level information. UC Davis developed Ribbon, which allows departments and campus administrators to look at migration in and out of STEM departments and between departments.[76] More than one-third of the STEM departments and several non-STEM departments now use the tool with many faculty members and professional advisors using it repeatedly. By 2017, more than 100 universities nationwide and internationally were using the tool to visualize student migrations as part of the Helmsley-funded Tools for Evidence-based Actions (TEA) project.

As the work of the Center for Educational Effectiveness (CEE), much of which is related to reforms begun under the aegis of the AAU project, has become known across the UC Davis campus, additional departments have started

72 Visualizing Instructional Practices and Observation Protocol for Learning Environments
73 Regina F. Frey, et al., A Visual Approach to Helping Instructors Integrate, Document, and Refine Active Learning, *The Journal of College Science Teaching* 45 (2016): 20-26.
74 Beth A. Fisher and Regina F. Frey, Using Documentary Tools to Foster the Practice of Scholarly Teaching, *The National Teaching and Learning Forum* 24 (2015): 4-6.
75James T. Laverty, et al., Characterizing College Science Assessments: The Three-Dimensional Learning Assessment Protocol, *PLOS ONE* 11 (2016): e0162333.
76 UC Davis Ribbon Tool

CASE STUDY

Harnessing Institutional Data

UC Davis has long been a leader in harnessing institutional data to identify, measure, and research factors that promote or inhibit the effectiveness of undergraduate education. Many of these efforts are currently centralized through the university's Center for Educational Effectiveness (CEE).

Part of this leadership has come through devising novel ways to get traditionally separate types of university data to work together to provide a fuller picture of the student experience. Another part comes from the development of powerful and intuitive data visualizations to display this information. Ribbon, for example, allows departments and campus administrators to look at migration in and out of STEM departments and between departments. More than 100 universities worldwide are currently using some form of this tool to visualize student migrations. CEE has also developed a Heat Map tool to identify courses with large DFW (drop, fail, withdraw) rates or courses that lead to disproportionately poor performance in subsequent courses.

CEE continues to develop tools for faculty and administrators. Many of the visualizations will soon be incorporated into the new campus Tableau server to facilitate secure delivery to department users. Know Your Students (KYS), for example, is intended to help faculty with their large courses by: 1) providing information about students' backgrounds and tips for engaging different types of students prior to the first day of class, 2) collecting and presenting targeted information on student out- comes during the course, and 3) aggregating, analyzing, and cataloging course outcomes in a teaching "portfolio" for reflection and use in the merit and promotion process. The first stage of pre-course information has been tested and iterated while the other two stages (MIDAS - Multidimensional Instructional Development for Achievement and Success) have received HHMI funding to develop.

The Diagnostic Department Dashboard (DDD), is meant for department- and campus-level administration and displays and helps interpret information about enrollment, diversity, retention, course "hot spots", student performance gaps, instructional staffing and more. This tool has been used formatively to assist various academic units in developing plans to improve student outcomes.

Beyond developing visualizations and tools, CEE has taken a strategic approach to using this information to bring about action. For example, DDD has been used in consultation, rather than being made independently available, to avoid misinterpretation and provide an opportunity to suggest relevant support services.

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The Ribbon Tool developed by CEE at UC Davis visualizes undergraduate students' educational pathways through courses and programs to inform department decision making.

collaborations with this unit. For example, the College of Agriculture has engaged in multiple studies of undergraduate student outcomes in programs including animal science, human development, environmental management, and agricultural economics. These studies focus on pre-requisites, troublesome large introductory courses, longitudinal course outcomes, retention of under-represented groups, development of course and program learning objectives, and online/hybrid course development. The departments of Communication, Economics, and Psychology have been involved in the development of hybrid and online courses with expanding plans for instructional research in the 2017-18 academic year.

The CU Boulder has undertaken an initiative called Data Analytics for Student Success and Educational Effectiveness (DASSEE). The tools developed in this project make it possible for departments and administrators to track impacts of courses and pathways of students across courses and address campus priorities for improving student retention, and diversity. Using Tableau as a

CONTINUED FROM PAGE 78

Underlying this approach is the understanding that while data by themselves may not change behavior, they can serve as the basis for conversations that will. Visualizations can help focus these conversations. Data must be understood in institutional context, and often more local context as well. While larger studies can highlight overall problems, issues, or trends, localized data (e.g., data about a single department or set of courses) is more effective and in influential in terms of bringing about specific action.

visualization platform, queries of the student information system can be performed focusing on a single course over time, a suite of courses in a given department or unit for a given semester, or a dashboard of individual student course grades by major over term. Key visualizations in the dashboard include representation of enrollment, grade distributions, pathways into a given course and following course, retention/persistence of students from a given course over time (in the major and institution). Subgroups can be selected by term, faculty instructor, demographics (including: an individual instructor offering of a course, gender, first generation status, ethnic/racial identification), and for subgroups receiving a given grade in a course.

Efforts to visualize student data have involved partnerships with Institutional Research (IR) and the Office of Information Technology to implement visualizations in Tableau. The goal is to create a suite of easily accessible data sets and associated visualizations of educational outcomes for undergraduates. Although these data already exist, they are not available in an easily accessible way. Similarly, at the UPenn, the Office of Institutional Research & Analysis (IR&A) is working with the Center for Teaching and Learning to establish a protocol for data requests from instructors assessing their courses. By developing assessment tools in the Center for Teaching and Learning and making them available to course instructors, UPenn has reduced the "time barrier" and encouraged more faculty members to use evidence-based instruction.

Keys to Successful Use of Data Analytics

1. *Distinguish between the types of data useful for individual faculty members designing and assessing their courses from the types of data used in departmental decision-making*. The key data influencing the faculty members (and chair) in the Chemistry and Molecular Biology Department at UA to adopt Chemical Thinking as the preferred introductory sequence in General Chemistry were the success of these students in subsequent courses; detailed within-course data on student learning outcomes demonstrated in the course were not important in the departmental decision. As another example, UNC-Chapel Hill and UPenn demonstrated decreases in Ds and Fs and course withdrawals from reformed courses. Departmental and university leadership were very interested in such data, particularly when underrepresented minorities showed differential improvement on these metrics.

2. *Ease and efficiency of use are keys to broad acceptance of teaching-related metrics*. CU Boulder DATs have emphasized commonly-used metrics on student outcomes, which makes dissemination and use in decision-making more likely. Linking IR into the data sharing process is also important.

3. *Data must be seen as part of the policy and decision-making process rather than as sufficient in their own right*. Among the more important

lessons learned on the use of data in educational reform took place at UC Davis. Initially the data analytics developed by UC Davis—which have broad appeal nationally and are quite widely used—were assumed to be sufficient to show faculty and administrators what worked and why. Over time it became clear to the CEE that passive presentation of data were not effective in promoting the redesign of courses and curricula. Rather, the CEE had to change its role to work more actively with academic units to devise strategies based on data analytics.

CASE STUDY

Collaborative Learning Spaces

The University of Arizona has focused some of its efforts to redesign classrooms into collaborative learning spaces (CLSs). Thanks to these recent efforts, the university currently has ten CLSs ranging in size from 30 to 264 student-seat spaces, and plans to redesign ten additional classrooms into CLSs ranging in size from 25 to 135.

One faculty member, Dr. Zoe Cohen from the Department of Immunology, documented her thoughts about participating in the AAU STEM Initiative and teaching in CLSs:

"I had been thinking about trying a "flipped" classroom for a while and decided to take the plunge and apply for one of the rooms. I was lucky enough to get accepted and spent the summer preparing for a completely new form of teaching. I taught Physiology of the Immune System (PSIO 431) to 160 students in the Science and Engineering Library in Fall 2015, and this experience not only changed me as an educator, it has opened opportunities to me to continue along this pathway. Once I started teaching in this room, I became involved in a Faculty Learning Community regarding the CLS as well as an Educational Faculty Learning Community. Through these, I was able to develop the materials to incorporate active learning (through discussions) within the classroom setting …. Based on teacher course evaluations and other comments, as well as looking at the overall grade distribution in the course (compared to previous semesters when the course was taught in a traditional lecture style), the changes made resulted in more active and meaningful engagement and understanding by the students."

Prof. Cohen has seen more As and Bs and fewer Ds and Es on the final exam since transforming her Physiology of the Immune System course. Her experiences match those of other faculty for different classes and departments (including physics, chemistry, molecular and cellular biology, and engineering), who also have seen positive impacts on student learning. These impacts include better grades and fewer failures, stronger performance on pre-post course tests, and better performance in follow-on courses.

AAU Learning Space Data

AAU collected data on campus infrastructure, including learning spaces, from project sites using the relevant sections of the PULSE Vision & Change Rubric. Given the expense and time-consuming nature of reconfiguring classroom spaces, AAU did not expect to see significant change in physical space over the three years of the project. However, institutions have made some progress in redesigning learning spaces.

The table shows the average aggregate response of institutions to each item during the first (2014) and second (2016) data collections, as well as the average aggregate response of Provosts during the second data collection. Interestingly, of the ten items, eight scored *lower* in 2016 than 2014. There are a few possible explanations. One is that these changes are due to differences in the sample. While comparisons between the first and second data collections are interesting, it is important to keep in mind that different departments are being compared, as well as different numbers of departments for each institution. Another possible explanation is that, over the course of the project, there were changes in attitudes leading to higher expectations. These self-reported rubric scores, especially when compared across time, may be at least as indicative of attitudes as they are of physical change.

The table also looks at differences between departmental and Provost views. The table shows that departments were more critical of learning spaces and resources and support; Provosts were slightly more critical with respect to physical infrastructure. The table also shows that for all but the last item (Institutional support for electronic resources: e.g., journal subscriptions and databases) there was a great range of differences in views across the eight universities.

Factor	2014 Aggregate Response	2016 Aggregate Response (Depts.)	2016 Aggregate Response (Provosts)
Physical Infrastructure			
Classrooms and teaching laboratories can accommodate special needs and differing abilities.	3.7	2.9	3.3
Access to flexible, re-configurable teaching spaces to encourage student interaction, ability to work in small groups.	2.5	1.8	2.0
Classroom IT infrastructure encourages active learning practices.	2.8	3.0	2.4
Access to intelligently designed laboratory space flexible enough to allow different uses that blur distinction between lecture and lab.	2.7	2.5	1.8
Equipment/supplies in teaching laboratories.	2.7	2.3	2.1
Learning Spaces			
Informal gathering spaces that encourage collaboration.	2.5	2.2	2.8
Learning Center for Students – for example, college-wide writing centers, learning centers or department level center with staff, tutor meeting rooms, TAs, computers and printers, study space for students.	3.2	2.5	3.3
Resources and Support			
IT support for innovative teaching, responds quickly to IT crisis; support includes hands-on technology training for faculty and proactive survey of new technology.	3.4	3.0	3.3
Staff support for teaching: administrative help to support teaching, lab managers/lab instructors, curriculum development/learning specialists, tenure-track faculty with education specialty.	2.6	2.4	2.9
Institutional support for electronic resources: e.g., journal subscriptions and databases.	3.9	3.9	4.0

NOTE: PULSE Vision & Change Rubric 1.0. Each response scored as 0 (not observed), 1 (initial stages), 2 (average), 3 (very good), 4 (excellent, exemplary). Information was collected after the first year of the three-year demonstration (2014) and at the end of the three years (2016). The sample in 2014 included five institutional averages and 9 departments at the other three schools (3 per school) that were averaged to make them comparable. The sample in 2016 included 33 individual departments across the eight universities, as well as scores provided by the Provosts at each institution, which were requested to contrast the view of a senior-level administrator with those of departments.

Learning Spaces

UA has devoted funding to redesigning classrooms into collaborative learning spaces (CLSs), including new furniture, additional projection equipment and other technology, carpeting, paint, and facilities work (including electrical upgrades, mounting projectors, etc.). Senior administrators have committed to three additional years of funding up to $1 million per year for new CLSs and other classroom and lecture hall improvements. These new spaces are needed to accommodate the desire for large collaborative classrooms (rooms for 130-250 student seats), since the institution has already targeted most of the large flat classrooms that can be converted to a CLS. The most popular CLSs are the larger rooms (90 to 264 seats). The university currently has ten CLSs ranging in size from 30 to 264 student-seat spaces, and its funded plan for summer, 2017 calls for ten additional CLSs ranging in size from 25 to 135.

The next new building on UA's campus is likely to be an engineering building, and the Dean of Engineering wants to include space for large collaborative classrooms. Administrators are also working to ensure that renovation of the Old Chemistry Building will include CLSs. Several department heads in STEM fields, including in chemistry and biochemistry, molecular and cellular biology, and several engineering departments, have become involved in space redesign with two associate heads on the leadership team. Several others have themselves taught in CLSs. For example, the department head of Chemical and Environmental Engineering co-taught with an engineering faculty member in a CLS; he supports team teaching in this facility.

UPenn created several active-learning classrooms to accommodate growing demand. At the start of the AAU project and the SAIL program, UPenn had only one 42-seat active learning room since then, they have added six more active classrooms, including three that accommodate between 72 and 90 students. All are fully scheduled throughout the year. One more collaborative classroom is planned, and faculty committees have asked the university to investigate further additions. The demand for and use of active learning rooms continues to grow, prompting the development of an additional active learning room in the Biomedical Library.

UNC-Chapel Hill is experimenting with new classroom furniture and configurations designed to make it easier for faculty members to use interactive learning methods. These classrooms facilitate eye contact between students, instructor access to students, and transitions between lecture, class discussion, and small group work. A series of classroom renovations are in progress across the campus to support active learning efforts. Since 2010, UNC-Chapel Hill has created sixteen active learning classrooms for general-purpose use. Early work featured small and mid-size classrooms including two smaller (45 seat) and one larger (90 seat) studio classrooms (larger round tables for student interaction). In 2015, the university's first interactive lecture hall (a 100-seat classroom renovation for active learning) was completed.

Others are in progress, including a large SCALE-UP classroom, indicating a significant institutional trend toward support of active learning.[77] To date, four primary designs have been used for active learning classrooms.[78]

At CU Boulder, the Provost's Learning Spaces Committee in 2016 developed design principles for educational spaces that were informed by the AAU Initiative. These guidelines have been inserted in the "stage-gate" design process, before plans are made, as the concept for new space is considered by campus.

Although redesigned learning spaces are not required for all forms of active learning, it can affect some applications directly. UC Davis, as an example, noted that implementation of active biological modeling in an introductory calculus course was highly negatively impacted by poorly designed instructional space. Discussion rooms that did not have tables where students could work together made group work and modeling exercises via computers logistically difficult and made it more difficult for students to complete the assignments.

Learning Assistants

Institutions have utilized both graduate and undergraduate students as teaching and learning assistants. Inclusion of students in instructional roles has benefits for institutions at the level of the course or section. With more trained individuals in the room, the capacity to facilitate and evaluate active learning activities increases. Including students also benefits the students themselves. Not only must they master the course material and develop familiarity with the objectives of various evidence-based learning techniques, but they also must put into play skills including leadership, evaluation and analysis, facilitation, and public speaking. Undergraduate learning assistants can play different roles in the classroom, with different levels of formality.

Across the eight project sites, use of graduate and undergraduate assistants in active learning classes more than doubled, from 740 to 1,676, during the three years of the AAU project.

Learning Assistants

	GRADUATE STUDENTS	UNDERGRADUATE STUDENTS	OTHER	TOTAL
Year 1	479	261	0	740
Year 2	649	278	4	931
Year 3	939	629	8	1676

77 SCALE-UP
78 Interactive Classrooms at UNC-Chapel Hill

WashU utilizes Peer-Led Team Learning (PLTL) in its general chemistry and calculus classes, and is translating the model for engineering courses. PLTL groups typically consist of 6-8 students who work together to solve problems, and are facilitated by a Peer Leader. Peer Leaders are undergraduate students who have previous taken and performed well in the course.[79]

WashU's model of PLTL is designed to help students become conscious of the problem-solving process. It also helps students develop important collaboration skills, including how to approach problems effectively as a group, how to communicate well, and how to exchange and critique ideas in a collaborative environment. Participation in PLTL is voluntary, and students who do participate commit, through a contract, to meeting specific obligations to their group. Peer Leader training is an important component of the program. All Peer Leaders enroll in two one-credit courses. In these two courses, Peer Leaders learn how to be strong mentors for their groups, and they form a collaborative group of their own to help one another address common PLTL challenges.

At UPenn, undergraduate learning assistants have been utilized in a similar way. For example, in introductory biology, two instructors restructured their large lecture into a hybrid active learning course with the help of undergraduate learning assistants. The hybrid biology course features traditional lecture two days a week, and a problem-based active-learning session once a week where students apply concepts or are introduced to new topics. The success of this format encouraged these instructors to further adapt the course; they plan to integrate shorter active moments into the lecture portions of the course, and formalize student group assignments to encourage more productive group work.

UA utilizes trained undergraduate learning assistants to help encourage student discussion (without giving the answer) and to help the instructor with formative assessment of student learning. At UA, as at several other institutions, undergraduate learning assistants are often students who have previously taken and done well in the course. They are given credit for acting as learning assistants and further develop their leadership skills, but they do not need to be paid.

One example of how UA uses undergraduates as learning assistants involves a measurement instrument called Fine-grained Evaluation of Active Learning (FEAL), which is designed for large classes in collaborative learning spaces.[80] FEAL is an activity quality measurement instrument that can be quickly administered by undergraduate learning assistants to record key measures of activity success such as student engagement, student success, activity difficulty, activity time, and associated lecture time. The instrument is designed to

79 PLTL at WashU

80 Sixing Ly, Loukas Lazos and Roman Lysecky, FEAL: Fine-Grained Evaluation of Active Learning in Collaborative Learning, paper presented at the American Society for Engineering Education Annual Conference & Exposition (June 25-28, 2017).

require minimal training and minimal effort within the classroom for recording observations. Quick administration of the instrument is critical because the learning assistants recording with FEAL are primarily tasked with engaging the students with the given activities. A key difference between FEAL and other tools (such as COPUS) is that the learning assistants must have expertise on the subject matter, as the intent is to evaluate activity quality. Moreover, relevant information such as the concepts covered by the activity are recorded and analyzed. The instrument is further applied to code exam questions and is used to correlate student performance for the same concepts.

MSU is increasing the number of graduate and undergraduate students who assist in teaching active learning classes. Funds for increased numbers of graduate and undergraduate learning assistants in the main introductory biology courses (cell and molecular biology, and organismal and population biology) have been made permanent. These additional assistants provide the resources necessary to facilitate more student-centered approaches in class meetings, as well as to implement more frequent assessments and feedback, especially on constructed-response tasks. In chemistry, resources for undergraduate learning assistants to support interactive engagement and the use of some constructed response assessment items in the lecture sections of general chemistry have been written into the departmental budget. This will be extended to organic chemistry in Fall 2017.

At UNC-Chapel Hill, the computer science department began utilizing undergraduate learning assistants to provide academic support to their peers in lectures, labs, office hours, and recitations, providing more individualized support to students while strengthening their own understanding of the course material in the process. According to the department's website: "Within two years, the learning assistants became the linchpin of the department's introductory courses." The department has introduced the Learning Assistant Award, which recognizes an undergraduate learning assistant who has shown outstanding dedication to helping their fellow students understand and master challenging course material.[81]

Department Support Structures

Another key to successful institutionalization of undergraduate instructional reforms is to align relevant administrative units, such as Centers for Teaching and Learning, with department-based instructional improvement efforts. For some institutions, this approach included linking advising and co-curricular units with classroom instruction. For others, it meant consolidating units to form a more effective organization. Providing college or campus-wide structures to support departmental reform efforts increased the likelihood of institutionalization in AAU project sites.

81 Computer Science Class Gets Modern Twist and Computer Science Learning Assistant Award

Structural innovations offer one type of solution. One alternative is to embed pedagogical expertise in each department by hiring, for example, LPSOEs at UC Davis. Another is to develop a teaching-oriented center staffed by respected senior tenure-track faculty members engaged in STEM reform such as MSU's CREATE for STEM Institute and WashU's CIRCLE. Brown provides another example, shifting the locus of control for STEM reforms from its Sheridan Center for Teaching and Learning (which remains highly engaged) to its academic departments.

More culturally-oriented reforms also can assist in enhancing the value placed on instructional improvement. CU Boulder uses DATs to move away from appeals to individual faculty members and toward group consensus for reform. UA's FLCs have been fundamental in promoting improved pedagogy and in institutionalizing reforms. This cross-department approach is especially important when many departments lack sufficient numbers of faculty members interested or trained in improving instruction and reforming curricula.

The AAU instructor survey also asked about use of on-campus and off-campus professional development opportunities focused on improving teaching. These percentages increased between the two survey administrations, showcasing instructors' additional interest in improving their teaching (see charts on page 89). ■

Instructor use of **on-campus** professional development opportunities.

On-Campus Professional Development Opportunity	2014 Users (%)	2016 Users (%)
Teaching development events (i.e. talks, workshops) specifically for instructors.	40.7%	55.7%
Teaching development opportunities and resources for NEW instructors.	23.0%	27.1%
Peer evaluations/feedback of teaching.	41.6%	48.9%
A mentor or other person to go to for advice about teaching.	45.2%	54.0%
A center or unit focused on teaching and learning within your college or school.	21.7%	29.9%
A university–wide center or unit focused on teaching and learning.	26.8%	37.7%
University resources for instructors to improve their teaching methods	27.7%	43.3%

Instructor use of **off-campus** professional development opportunities.

Off-Campus Professional Development Opportunity	2014 Users (%)	2016 Users (%)
Teaching development events (i.e. talks, workshops) specifically for instructors.	14.0%	20.6%
Teaching development opportunities and resources for NEW instructors.	4.4%	7.4%
A mentor or other person to go to for advice about teaching.	14.8%	20.6%
A cohort of scholars focused on teaching and learning.	11.7%	20.7%
Resources for instructors to improve their teaching methods.	18.6%	28.2%

CASE STUDY

Center for Integrated Research in Cognition, Learning and Education

The mission of the Center for Integrative Research on Cognition, Learning, and Education (CIRCLE) at WashU is to provide a bridge between STEM faculty and researchers in the cognitive and learning sciences to facilitate collaborative projects to improve student learning. The Center connects the cognitive and learning sciences with classroom practices by:

- fostering implementation of innovations in teaching across the university
- supporting research to evaluate the effectiveness of these innovations in enhancing student learning and retention of knowledge, and
- disseminating the results of these classroom-based evaluations using experimental methods to the university community as well as the to the national and international teaching and learning communities.

CIRCLE was founded in 2011. It is funded by the Office of the Provost, though its leadership consists of STEM faculty members, which gives it particular cachet with departmental faculty and staff, with whom it operates in a partner role than rather than as a support structure. CIRCLE serves as a coordinating body for many STEM education-related activities on campus, including faculty learning communities and the Faculty Fellow program. The Center works on efforts that are part of the AAU Initiative, as well as those that fall outside the project.

The center recently obtained a four-year commitment to support its new Transformation for innovation in STEMS (TIES), which is adapted from Carl Wieman's University of Colorado Boulder Science Education Initiative.

CASE STUDY

CREATE for STEM Institute

CREATE for STEM is a Michigan State University sponsored research institute with a broad mandate for Collaborative Research in Education, Assessment and Teaching Environments for the STEM fields. The Institute is a collaboration between the colleges of Education, Natural Science, Engineering, and the Lyman-Briggs Residential College in coordination with the Office of the Provost.

CREATE for STEM was implemented and endowed with university funds to coordinate educational activities across campus. (These activities include those associated with the AAU project as well as others not associated with the project.) The Institute brings together STEM faculty and faculty from the College of Education and serves as a springboard and hub for innovation, research, and intellectual collaboration to help bring to fruition ideas and projects that will make a difference in the teaching and learning of STEM for all learners. The Institute's work has five major focus areas:

1. creating and investigating change in K-16 STEM education,
2. educational policy in STEM fields,
3. discipline-based undergraduate STEM education,
4. developing innovative and digital materials, and
5. international engagement with the global STEM education community.

Within each of these areas, the Institute builds interdisciplinary and intergenerational research groups, fosters new talent, provides seed money for initial work, and supports the grant writing process. CREATE for STEM is also a hub for the exchange of information and ideas, sponsoring conferences, workshops, seminars, and visiting scholars to enhance the interest in STEM education and develop capacity in these fields here at MSU.

One key feature of the Institute that distinguishes it from many other teaching and learning centers is that rather than being staffed administrators, it houses respected tenured and tenure-track faculty members engaged in STEM reform. This provides a different relationship between the Institute and departments.

Cultural Change

Department Ownership of the Curriculum

One key to improving undergraduate STEM education is for a department and its faculty members to recognize and acknowledge their collective responsibility to improve the effectiveness of introductory/foundational courses. In a research university achieving such a departmental commitment is challenging both because many (sometimes most) of the students taking these introductory courses will not major in the department offering them and because the attractions and rewards of research universities for faculty members most often are in research and graduate education.

AAU has observed that departments most likely to emphasize evidence-based active-learning strategies in foundational courses have thought deeply about the curricula and content of these courses, along with ways to assess student learning in them. Ultimately, collective responsibility for shared learning objectives by course will necessitate developing a uniform vision of educational improvement among faculty members within and across departments, as well as the development of mechanisms to assess progress in teaching effectiveness for all students.

Consider the Biology Initiative at MSU as an example of this process. The Biology Initiative focused on introductory genetics, which serves three colleges and 18 majors. No single college or department "owned" the course, which made it difficult to assign teachers, develop common learning objectives, and assess results. Funded by the Provost and coordinated with the AAU project at MSU, the first step in this reform initiative was to create a management committee. The committee, which reported to the Dean of Natural Sciences, was responsible for introductory genetics, including the assignment of instructors and the development a set of common learning objectives. This arrangement increased cross-department communication and led to more coordinated instructional and assessment practices. Follow-up assessment showed a substantial increase in student performance relative to the prior format of introductory genetics.

As another example, at UC Davis, the Colleges of Bioscience, Agriculture, and Environmental Science, as well as the Department of Chemistry, recently developed a shared five-course sequence for students in the Life Sciences (piloted in Fall 2017 with the initial work on three quarters). This collaboration represents the first time that such a diverse group of faculty members and departments cooperated to develop new courses and a course sequence. UC Davis then linked its summer bridge program with the new curricular sequence and identified discrete paths for students to take chemistry courses based on their interests and intended majors.

Since the start of the AAU project, UNC-Chapel Hill has transformed all of its introductory courses in Biological Sciences in a manner consistent with evidence-based pedagogies. Physics as a department opted to reform all introductory courses in a similar manner. One key: Regardless of instructor there will be common materials and examinations in these introductory courses.

Among the most visible evidence of departmental ownership of courses and curricular is at Brown. The project initially was housed in the Sheridan Center for Teaching and Learning with the Director playing a lead role in the project. When the Director unexpectedly left, the chairs in key STEM departments took responsibility for the project and made sure that the departments took responsibility for course and curriculum improvements.

Institutional Commitment to Long-term STEM Reforms

Institutionalizing reforms of undergraduate STEM education at research universities eventually requires internal institutional investment of resources; it cannot be achieved solely by a series of externally-funded grants. The nature of this investment can vary, supporting personnel, infrastructure, and/or space. Public pronouncements of support by university leaders are also important contributions to the spread of instructional reforms across departments.

Each of the eight project sites has garnered institutional support for long-term STEM undergraduate reforms. At Brown, the Office of the Provost has continued its pledge of budgetary support for the project despite turnover in that position. The Provost and dean have committed institutional resources to assist participating departments in reforming introductory STEM courses (including hiring and training Teaching Assistants). In addition to financial resources, the central administration has made public pronouncements in support of the AAU STEM reforms and has engaged with project activities. Brown also has modified some teaching spaces to better reflect the use of active learning techniques. The most significant long-term commitment, however, is signified by the hiring of a specialist, working in the Sheridan Center for Teaching and Learning, who will help train problem-solving group facilitators. This move by the university is part of an emerging project to sustain and strengthen the culture of problem-solving created by the AAU project. The project is a large-scale, joint effort between the Sheridan Center, the Office of the Dean of the College, and the STEM department chairs and faculty.

At MSU, the Provost, deans, and chairs have made efforts to encourage academic programs to hire individuals knowledgeable about evidence-based teaching. Chemistry hired an individual whose sole job focus is to support curriculum transformation. Also in Chemistry, the Provost provided funds for undergraduate learning assistants (ULAs) and is funding the alteration of classroom space. The Provost funded new graduate and undergraduate teaching assistants for introductory biology courses. Three new course curriculum coordinators were hired with university funds; their focus is on the introductory sequence in biology. Physics hired several ULAs for teaching introductory courses.

At UPenn, one key to increasing the number of faculty involved and institutional support has been the evidence of success—students taking reformed courses achieve better than those taking traditional courses and seem to persist in STEM as well (the evidence of this outperformance is especially strong in bioengineering and physics). The evidence of improved student performance has led faculty and chairs to vote to sustain the SAIL classroom reform model. UPenn has also received central administrative support for building new classrooms that fit active learning instructional strategies.

Despite substantial institutional budgetary constraints, UA received a pledge to continue funding of the core faculty learning community and workshop efforts. UA leaders have also contributed resources to reform classrooms and provide salary for some teaching-related positions. Central administrators also have regularly reported on the AAU project achievements in campus news outlets. UA commitment of resources to long-term reforms include funds for a new Center for University Educational Scholarship (including a director and three fellows).

Extensive turnover by senior university leadership at CU Boulder in recent years, makes it difficult to assess the stability of long-term commitments to reform by central administration. However, CU Boulder received institutional funds for three new STEM teaching-oriented faculty hires and the central administration now requires departments to answer three questions about its effectiveness. This signals that the central administration is cooperating with AAU project goals.

The central administration and various colleges at UC Davis now contribute funds to support the STEM reforms started by the AAU project. For example, the Colleges of Biology and Agriculture now support the continued reform of Chemistry III. The Provost now commits money for the CEE, multiple faculty learning communities, an evidence-based course redesign institute, and course design awards.

Department Effectiveness Questions

How does your department define excellence with respect to the activities that it carries out and what values and behaviors are associated with excellence?

How do the efforts within the department lead to the inclusion of all students in achieving academic success, student social development, and enhancing the reputation of the department and the university?

Given the department's definition of excellence and inclusion, how will the department attain inclusive excellence?

UNC-Chapel Hill provides an example of the investment of resources at the precise time needed to expand reforms: The Provost and several Deans agreed to contribute university funding to continue the course buy-out strategy (i.e., both mentors and apprentices get a full course credit for co-teaching one course) after AAU funds disappeared, which enabled UNC-Chapel Hill to expand the numbers of participants in its STEM reform programs. Beyond its support for the original AAU grant, UNC-Chapel Hill central administration now supports salaries for five STEM instructors experienced in Discipline Based Education Research (DBER) and evidence-based teaching, the Chancellors Scholars program (for minority students), summer teaching institutes for faculty members, and classroom renovations. In addition, the Quality Enhancement Program (QEP) at UNC-Chapel Hill has been funded until at least 2022. The QEP will take over the work started by the AAU project after funding ends.

The substantial resource commitment to CIRCLE is indicative of an institutional commitment to the overall reform of STEM education at WashU. CIRCLE recently obtained a four-year commitment to support its new Transformational Initiative for Education in STEM (TIES), which is adapted from Carl Wieman's Science Education Initiative. The Chemistry Department has also funded a permanent position to disseminate and institutionalize educational reforms in that department.

Leveraging Other Undergraduate Reforms on Campus

Project sites successfully leveraged existing undergraduate reform efforts in their efforts to broaden the reform of STEM education. Taking advantage of resources already committed to other types of educational reforms, either from external grants or from internal sources, was a common theme. MSU was able to leverage various ongoing projects to create a larger, more visible, and longer-lasting presence on campus.

Better coordination of various administrative units responsible for undergraduate education also was evident. Successful forms of coordination included linking advising and co-curricular units with classroom instruction as well as consolidating units to form a more effective organization. UC Davis is a prime example of the latter. UC Davis has given greater visibility to educational reform efforts on campus by merging the iAMSTEM Center with the Center for Excellence in Teaching and Learning (CETL) to form the Center for Educational Effectiveness (CEE) and providing funds for CEE staff.[82] CEE is now supported with regular university funds and works with Student Affairs Administration (SAA) to combine non-curricular information about students with classroom data to better identify factors in student success.

Linking STEM educational reforms with university initiatives also proved successful. As a prime example, at UNC-Chapel Hill, the Chancellor's Strategic

82 UC Davis Center for Educational Effectiveness

Framework now requires all 13 schools and their departments to show evidence of high impact research *and* innovative teaching. The Quality Enhancement Program (QEP) promoted by central administration includes a focus on improving undergraduate STEM education. The UNC-Chapel Hill project also has emphasized the improvement of academic performance and degree retention among underrepresented minorities, which is a university priority.

Demonstrating more effective ways to measure the quality of teaching also has been used to support institutional and state-wide efforts to improve teaching. As an example, at UA, the AAU project has taken advantage of university resources for improving teaching and learning, incorporating activities and staff into an overall STEM reform movement. Two additional NSF grants have supported an expansion of AAU project-initiated efforts. Finally, the UA team has cited state-level policy emphasizing the quality of education on public campuses to promote STEM reforms at UA.

All project sites were able to leverage the reputation of AAU in extending the visibility of their projects. Also, membership in other national networks enabled project sites to leverage external support for local reforms.[83]

Institutional Commitment to Align Faculty Rewards to Evidence-based Teaching Practices

A primary goal of this initiative was to bring about a shift in the culture of research universities to increase the use and valuing of evidence-based instruction to the point where it became the norm rather than the province of a dedicated few. AAU was aware that mainstreaming evidence-based pedagogy would require aligning the faculty reward structure with (often) new expectations for teaching, realigning rewards to reinforce an expectation for teaching excellence consistent with the use of evidence-based instruction. Of all the project goals, changing faculty rewards to increase the value of teaching has been the most difficult. Despite AAU's expectation as expressed in the proposal process, only two of the eight project sites proposed actual plans to work on the routines by which their campus normally addressed merit, promotion, and tenure judgments, including taking this up with the political entities, like faculty senates, that would have to be on board for widespread change to occur.

In spite of this lack of emphasis by projects on and the apparent resistance to systematically address this aspect of culture change, AAU saw clear trends over the years toward aligning the institutional incentive structure with support of evidence-based teaching. For example, Physics at MSU now requires every pre-tenured faculty member to have at least one formal observation by a trained professional (in evidenced-based teaching) each semester. Tenured faculty members must do so at least once per year. These findings are now an official part of the faculty dossier in Physics. CU

83 CIRTL Network

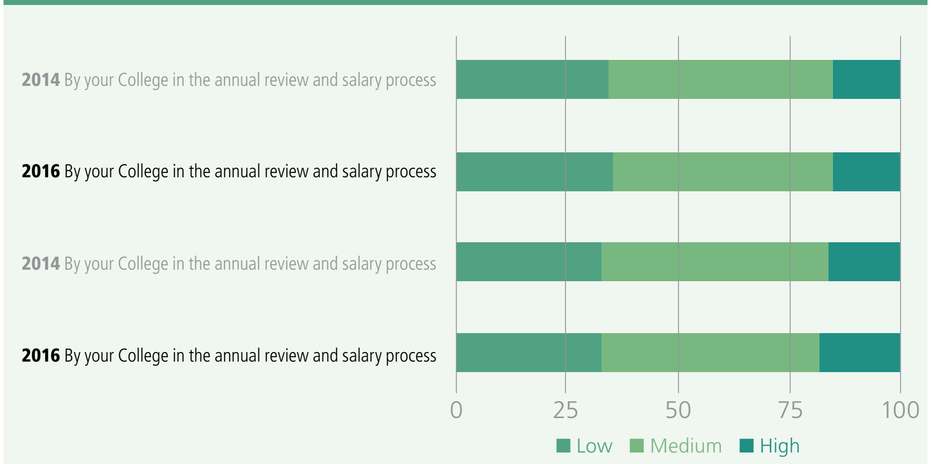
Boulder reformed its institutional requirements for departmental and faculty performance to include excellence in teaching. At WashU, for promotion and tenure, the Schools of Arts and Science and Engineering and Applied Science now require faculty members submitting materials for performance review to include details about their teaching and participation in professional development activities (teaching certificates from CIRCLE are helpful in this regard). In the past only student course ratings were required for faculty review. At UA the promotion and tenure process at the university level has been modified to include a required teaching portfolio and peer assessment/observation of classroom instruction. In the future as part of its regional accreditation and monitoring by The University of Arizona higher learning commission, UA will gather data on the use of evidence-based teaching and the quality of instruction. UNC-Chapel Hill similarly will gather data on teaching and learning as part of its regional accreditation.

AAU used two data sets for drawing more general inferences about the place of evaluation and assessment of teaching in judging faculty for merit, promotion, and tenure. As noted above, information about this was requested in the annual reports. Second, in each of the two rounds of common data collection across the sites (2014 and 2016), this issue was addressed in two ways. The survey included questions that elicited faculty perception of how this work is valued by their department and institution.

- Perceptions of recognition of importance of teaching by departmental and campus administrators (>3.0) out of sync with perceptions of the role effective teaching plays in annual review and salary (≈2.5).

- Most felt quality of evidence for teaching used was of low (about 33%) or medium (about 50%). Only about 15% judged the quality high.

How would you rate the quality of evidence for teaching used in the following circumstances?



CASE STUDY

Teaching Quality Framework

One of the barriers to including information about teaching in tenure and promotion decisions is the lack of a scholarly approach to teaching evaluation. The University of Colorado Boulder is developing a Teaching Quality Framework (TQF) to address this shortcoming and provide a common campus-wide framework for evaluating teaching quality that is contextualized to and enacted within varying disciplines, units, and roles. The TQF effort will empower and support departments to define the multiple measures that specify teaching quality in a way that is evidence-based, draws from leading scholarship on educational practices and evaluations, and is relevant to individual domains. The goal of the framework is both to provide better mechanisms for assessing teaching quality for merit, tenure, and promotion and to support improved teaching by providing faculty members with feedback that they can use to improve as educators.

The TQF defines a professional approach to teaching as including: clear goals, adequate preparation, appropriate methods, significant results, effective presentation, and reflective critique. These form the assessment categories for the framework, which are the same across all departments. However, interpretation of these categories and their relative weights are defined at the departmental level. Within each category, quality of teaching is assessed using three standard sources: the faculty member, students, and peers.

Implementing the TQF follows an opt-in model, with pilot departments choosing to engage and become leaders in this process. Two layers of action advance this initiative. First, departmentally based TQF Teams consist of three to six participants per department, who meet regularly and approach their work using a Departmental Action Team model (see separate call-out box). These teams contextualize the elements of the framework in their discipline and decide what is required for implementation in their department. Second, a campus-wide TQF Taskforce includes a broad set of participants (departmental representatives, deans, and other key stakeholders) who incorporate changes into the overall framework and communicate among departmental teams and other stakeholders. Key to the program's success is a facilitator of the multiple departmental TQF teams who also serves as a communication channel between those teams and the campus taskforce.

To date, nine departments are committed to the process. These departments include humanities, social sciences, natural sciences, and engineering. An additional four departments have expressed interest. A campus-wide community has met each semester to discuss the TQF process and the resources to support its continuing implementation.

The heads of participating departments were asked to write brief statements about how teaching is evaluated and valued in their department. In 2014, 30 department chairs from seven of eight institutions responded. In 2016, 30 department chairs from eight institutions responded. In both years, respondents asserted that teaching is highly valued. Many of them quoted university level or college level language to this effect. Most provided some level of detail about their process for collecting information and providing feedback to faculty.

Student evaluations at the end of courses were overwhelmingly the metric used in 2014. Faculty personal statements, review of course materials, and observation also played some role, especially in tenure decisions. It was not possible to tell from most of the department head statements whether these additional criteria made any explicit address to use of evidence-based instructional methods. In 2016, student evaluations were still the major metric, but there were two statements that could be taken as critiques of their usefulness. One of these is mild – a chemistry department notes that "scores will be considered, but not weighted heavily unless they are extraordinarily positive or negative." The other is more robust – a mathematics department is engaged in a debate over whether to use them at all, given the literature on implicit bias and other confounding elements in their use.

By 2016 most departments mention some level of peer observation, but in only a few cases was it clear that observers would use tools that helped them go beyond their own experience. Many departments expect that tenure review will include a portfolio that contains representative course materials.

In 2016, twelve of the 30 made explicit reference to evidence-based pedagogy as an important criterion for tenure track faculty, and two more included it for non-tenure track faculty but not tenure track, as compared with six and two respectively out of 30 in 2014. Eight had statements classified as permissive, that is, allowing faculty to present use of evidence-based work without implying it is expected, compared to six in 2014. Binning the ranges shows that attention to this was evident in 73% of the responses in 2016, compared to 47% in 2014. Three among the ones noted above for 2016 specifically mentioned student outcomes as a criterion: one provided no detail, another tracks student success in later courses, and the third tracks assessment of achievement of learning goals that have been agreed by the department.

Between 2014 and 2016 there was a shift in the tone of the responses that, taken collectively, points to culture change, at the very least at the level of chairs being more willing to think beyond the cookbook answers to the presenting question. For example, there was more of a tendency for the chair to say or imply that keeping a focus on good teaching is an important part of the chair's role. The statements from one institution (five departments) all emphasized, and took pride in, their use of the resources of their Teaching Center. Finally, some chairs took the question as an invitation to comment on culture change more generally and spoke of seminar presentations and an increase in department conversations about teaching, as well as named awards for teaching.

There were cases in which an aspect of the site's AAU project plan was particularly evident in the response. These include CU Boulder's beginning to introduce very explicit expectations of an effort to use evidence-based pedagogy in the merit review criteria; and UPenn Math Department's very robust reexamination of the use of student ratings and alternative metrics, based on their experiments in introductory math. Another institution, on the other hand, presented a striking difference between the focus of the project leadership, which has tended to espouse the view that faculty motivation to change is intrinsic and not driven by the institutional reward system, and the responses from its chairs which also cite its Natural Sciences college-wide resources. The College policy is explicit in its criteria in a way that points to use of modern pedagogy as desirable.

In general, the trends observed in the department heads surveys are echoed in the annual reports from project leadership, although not perfectly, as noted above. It is useful to note that the last five years have seen the appearance of significant new tools for peer observation and self-analysis of teaching practice, so that it is easier now for a department that seeks alignment of incentives with good practice to begin to articulate what is needed. Examples of new approaches are presented in this section and in section 3, which come not only from a funded project site but several members of the larger AAU network. ■

AAU STEM Project Site Scholarship

This section lists the peer reviewed scholarship that has been generated by the AAU Project Site Teams. The citations are categorized by their area of focus: Policies and Strategies; Elements of Active Learning; Practical Steps to Improve Undergraduate Education; and Instructional Personnel.

Policies and Strategies

Institutional Strategies to Increase the Value of Improving Undergraduate Teaching

Corbo, J. C., Reinholz, D. L., Dancy, M. H., Deetz, S., & Finkelstein, N. (2016). Framework for transforming departmental culture to support educational innovation. *Physical Review Physics Education Research, 12*(1), 010113. http://dx.doi.org/10.1103/PhysRevPhysEducRes.12.010113

Corbo, J. C., Reinholz, D.L., Dancy, M. H. and Finkelstein, N (2015). Departmental Action Teams: Empowering Faculty to Make Sustainable Change, in Physics Education Research Conference 2015 (College Park, MD, 2015). http://dx.doi.org/10.1119/perc.2015.pr.018

Fairweather, J. S., Trapani, J., & Paulson, K. (2016). The roles of data in promoting institutional commitment to undergraduate STEM reform: The AAU STEM Initiative experience. In G. C. Weaver, W. D. Burgess, A. L. Childress, & L. Slakey (Eds.), *Transforming institutions: Undergraduate STEM education for the 21st century* (pp. 429-437). West Lafayette, IN: Purdue University Press.

Macfadyen, L. P., Groth, D., Rehrey, G., Shepard, L., Greer, J., Ward, D., Bennett, C., Kaupp, J., Molinaro, M., & Steinwachs, M. (2017). Developing institutional learning analytics 'communities of transformation' to support student success. Paper presented at the Seventh International Learning Analytics & Knowledge Conference, March 13-17, Vancouver, British Columbia, Canada. Retrieved from http://bayviewalliance.org/bvwwp/wp-content/uploads/2016/11/LA_Fellows_workshop_V3.0.pdf

Matz, R. L., & Jardeleza, S. E. (2016). Examining the Role of Leadership in an Undergraduate Biology Institutional Reform Initiative. *CBE-Life Sciences Education, 15*(4)

Miller, E. R., & Fairweather, J. S. (2016). The role of cultural change in large scale STEM reform. In G. C. Weaver, W. D. Burgess, A. L. Childress, & L. Slakey (Eds.), *Transforming institutions: Undergraduate STEM education for the 21st century* (pp. 48-66). West Lafayette, IN: Purdue University Press.

Pagliarulo, C., & Molinaro, M. (2015). iAMSTEM: Increasing STEM success at UC-Davis. *Peer Review, 17*(2), 13. Retrieved from https://www.aacu.org/peerreview/2015/spring/pagliarulo.

Weaver, G. C., Burgess, W. D., Childress, A. L., Slakey, L. (Eds.). (2016). *Transforming Institutions: Undergraduate STEM education for the 21st century.* West Lafayette, IN: Purdue University Press. http://www.thepress.purdue.edu/titles/format/9781557537249

Policies and Strategies to Encourage the Use of Effective Teaching Practices

Burd, G. D., Tomanek, D., Blowers, P., Bolger, M., Cox, J., Elfring, L., Grubbs, E., Hunter, J., Johns, K., Lazos, L., Leysecky, R., Milsom, J. A., Novodvorsky, I., Pollard, J., Prather, E., Talanquer, V., Thamvichai, K., Tharp, H., & Wallace, C. (2016). Developing faculty cultures for evidence-based teaching practices in STEM: A progress report. In G. C. Weaver, W. D. Burgess, A. L. Childress, & L. Slakey (Eds.), *Transforming institutions: Undergraduate STEM education for the 21st century* (pp. 90-102). West Lafayette, IN: Purdue University Press.

Hogan, K. A., Krumper, J., McNeil, L. E., & Crimmins, M. T. (2016). Advancing evidence-based teaching in gateway science courses through a mentor-apprentice model. In G. C. Weaver, W. D. Burgess, A. L. Childress, & L. Slakey (Eds.), *Transforming institutions: Undergraduate STEM education for the 21st century* (pp. 77-89). West Lafayette, IN: Purdue University Press.

Reinholz, D. L., Corbo, J. C., Dancy, M. H., Finkelstein, N., & Deetz, S. (2016). Towards a model of systematic change in university STEM education. In G. C. Weaver, W. D. Burgess, A. L. Childress, & L. Slakey (Eds.), *Transforming institutions: Undergraduate STEM education for the 21st century* (pp. 115-124). West Lafayette, IN: Purdue University Press.

Practical Steps to Improve Undergraduate Education: Curricula and Assessment

Assessment of Undergraduate Student Learning

Becker, N., Noyes, K., & Cooper, M. (2016). Characterizing students' mechanistic reasoning about London dispersion forces. *Journal of Chemical Education, 93*(10), 1713-1724. http://dx.doi.org/10.1021/acs.jchemed.6b00298

Cooper, M. M. (2015). Why ask why? *Journal of Chemical Education*, *92*(8), 1273-1279. http://dx.doi.org/10.1021/acs.jchemed.5b00203

Cooper, M. M., Caballero, M. D., Ebert-May, D., Fata-Hartley, C. L., Jardeleza, S. E., Krajcik, J. S., Laverty, J. T., Matz, R. L., Posey, L. A., & Underwood, S. M. (2015). Challenge faculty to transform STEM learning. *Science*, *350*(6258), 281-282. http://dx.doi.org/10.1126/science.aab0933

Cooper, M. M., Kouyoumdjian, H., & Underwood, S. M. (2016). Investigating students' reasoning about acid–base reactions. *Journal of Chemical Education, 93*(10), 1703-1712. http://dx.doi.org/10.1021/acs.jchemed.6b00417

Cooper, M. M., Williams, L. C., & Underwood, S. M. (2015). Student understanding of intermolecular forces: a multimodal study. *Journal of Chemical Education, 92*(8), 1288-1298. http://dx.doi.org/10.1021/acs.jchemed.5b00169

Cooper, M. M. (2016). It is time to say what we mean. *Journal of Chemical Education*, *93*(5),799-800. http://dx.doi.org/10.1021/acs.jchemed.6b00227

Cooper, M. M., Posey, L. A., & Underwood, S. M. (2017). Core ideas and topics: Building up or drilling down? *Journal of Chemical Education, 94*(5), 541-548. http://dx.doi.org/10.1021/acs.jchemed.6b00900.

Irving, P. W., Sawtelle, V. D., & Caballero, M. D. (2015). Troubleshooting Formative Feedback in P^3 (Projects and Practices in Physics). Paper presented at the Physics Education Research Conference, July 29-30, College Park, MD. http://dx.doi.org/10.1119/perc.2015.pr.034

Laverty, J. T., Underwood, S. M., Matz, R. L., Posey, L. A., Carmel, J. H., Caballero, M. D., Fata-Hartley, C. L., Ebert-May, D., Jardeleza, S. E., & Cooper, M. M. (2016). Characterizing College Science Assessments: The Three-dimensional Learning Assessment Protocol. *PLOS ONE*, *11*(9), e0162333. http://dx.doi.org/10.1371/journal.pone.0162333

Underwood, S. M., Reyes-Gastelum, D., & Cooper, M. M. (2015). Answering the Questions of Whether and When Learning Occurs: Using Discrete Time Survival Analysis to Investigate the Ways in Which College Chemistry Students' Ideas About Structure–Property Relationships Evolve. *Science Education, 99*(6), 1055-1072. http://dx.doi.org/10.1002/sce.21183

Williams, L. C., Underwood, S. M., Klymkowsky, M. W., & Cooper, M. M. (2015). Are Noncovalent Interactions an Achilles Heel in Chemistry Education? A Comparison of Instructional Approaches. *Journal of Chemical Education, 92*(12), 1979-1987. http://dx.doi.org/10.1021/acs.jchemed.5b00619

Course (Re-)Design and Student Learning Outcomes

Crimmins, M. T., & Midkiff, B. (2017). High structure active learning pedagogy for the teaching of organic chemistry: Assessing the impact on academic outcomes. *Journal of Chemical Education, 94*(4), 429-438. http://dx.doi.org/10.1021/acs.jchemed.6b00663

Dockter, D., Uvarov, C., Guzman-Alvarez, A., & Molinaro, M., (in press). Improving preparation and persistence in undergraduate STEM: Why an online, summer chemistry preparation course makes sense. Forthcoming ACS Publication, *Online Approaches to Chemical Education*, Manuscript ID: bk-2016-005344.

Dourte Segan, L., & Elliott, E. R. (2016). Group problem solving coupled with hands-on activities: Conceptual gains and student confidence in an introductory biomechanics course. Paper presented at the American Society for Engineering Education Annual Conference & Exposition, June 26-29, New Orleans, LA. Retrieved from https://www.asee.org/public/conferences/64/papers/16930/view

Dourte Segan, L., & Ilkhanipour Rooney, S. (2015). Structured, active, in-class learning: Connecting the physical to the mathematical in an introductory biomechanics course (work in progress). Paper presented at the American Society for Engineering Education Annual Conference & Exposition, June 14-17, Seattle, WA. Retrieved from https://peer.asee.org/24745

Eddy, S. M., & Hogan, K. A. (2014). Getting under the hood: How and for whom does increasing course structure work? *CBE—Life Sciences Education, 13*(3), 453-468. http://dx.doi.org/10.1187/cbe.14-03-0050

Irving, P. W., Obsniuk, M. J., & Caballero, M. D. (2016). P^3: A Practice Focused Learning Environment. arXiv:1607.04455 [physics.ed-ph]. Retrieved from http://arxiv.org/abs/1607.04455.

Molinaro, M., Steinwachs, M., Li, Q., & Guzman-Alwarez, A. (2016). Promoting instructor and department action via simple, actionable tools and analyses. Paper presented at the Learning Analytics for Curriculum and Program Quality Improvement Workshop co-located with the Sixth International Learning Analytics and Knowledge Conference, April 25, Edinburgh, United Kingdom. Retrieved from: http://ariadne.cti.espol.edu.ec/pcla2016/files/ProceedingsPCLA2016.pdf

Rainey, K., Corbo, J. C., Reinholz, D. L., and Betterton, M. Improving Representation in Physical Sciences using a Departmental Action Team, in Physics Education Research Conference 2016 (Sacramento, CA, 2016). http://dx.doi.org/10.1119/perc.2016.pr.061

Solomon, E. D., Cohen, C. A., Cahill, M. J., McDaniel, M. A., Zhao, J., & Frey, R. F. (in review). Examining the impact of student characteristics: Active learning with clickers predicts performance in an introductory science curriculum. *CBE-Life Sciences Education*. Manuscript submitted May 2017.

Underwood, S. M., Reyes-Gastelum, D., & Cooper, M. M. (2016). When Do Students Recognize Relationships Between Molecular Structure and Properties? A Longitudinal Comparison of the Impact of Traditional and Transformed Curricula. *Chemistry Education Research and Practice, 17*(2), 365-380. http://dx.doi.org/10.1039/C5RP00217F

Laboratory Instruction in STEM

Carmel, J. H., Ward, J. S., & Cooper, M. M. (2017). A Glowing Recommendation: A Project-Based Cooperative Laboratory Activity to Promote Use of the Scientific and Engineering Practices. *Journal of Chemical Education*, *94*(5), 626-631. http://dx.doi.org/10.1021/acs.jchemed.6b00628

Elements of Active Learning

Collaborative Small-Group Learning

Obsniuk, M. J., Irving, P. W., & Caballero, M. D. (2015). A Case Study: Novel Group Interactions through Introductory Computational Physics. Paper presented at the Physics Education Research Conference, July 29-30, College Park, MD. http://dx.doi.org/10.1119/perc.2015.pr.055

Trenshaw, K. F., Targan, D. M., & Valles, J. M. (2016). Closing the achievement gap in STEM: A two-year reform effort at Brown University. Paper presented at the American Society for Engineering Education Northeast Section Conference, April 28-30, Kingston, Rhode Island. Retrieved from http://egr.uri.edu/wp-uploads/asee2016/73-1064-1-DR.pdf

Creating Learning Resources

Allen, G., Guzman-Alvarez, A., Smith, A., Gamage, A., Molinaro, M., & Larsen, D. S. (2015). Evaluating the effectiveness of the open-access ChemWiki resource as a replacement for traditional general chemistry textbooks. *Chemistry Education Research and Practice, 16,* 939-948. http://dx.doi.org/10.1039/C5RP00084J

Instructional Personnel

Training Graduate Teaching Assistants

Becker, E. A., Easlon, E. J., Potter, S. C., Guzman-Alvarez, A., Spear, J. M., Facciotti, M. T., Igo, M. M., Singer, M., & Pagliarulo, C. *(Manuscript submitted for publication).* The effects of practice-based training on graduate teaching assistants' classroom practices. *CBE—Life Sciences Education.* http://dx.doi.org/10.1101/115295

Ilkhanipour Rooney, S., Schafer McGurk, J., Elliott, E. R., Williams, U. J., & Dourte Segan, L. (2015). Facilitating the transition of a traditional engineering course to a structured, active, in-class learning environment as a teaching assistant. Paper presented at the American Society for Engineering Education Annual Conference & Exposition, June 14-17, Seattle, WA. Retrieved from https://peer.asee.org/24092

Evaluating Teaching Practices

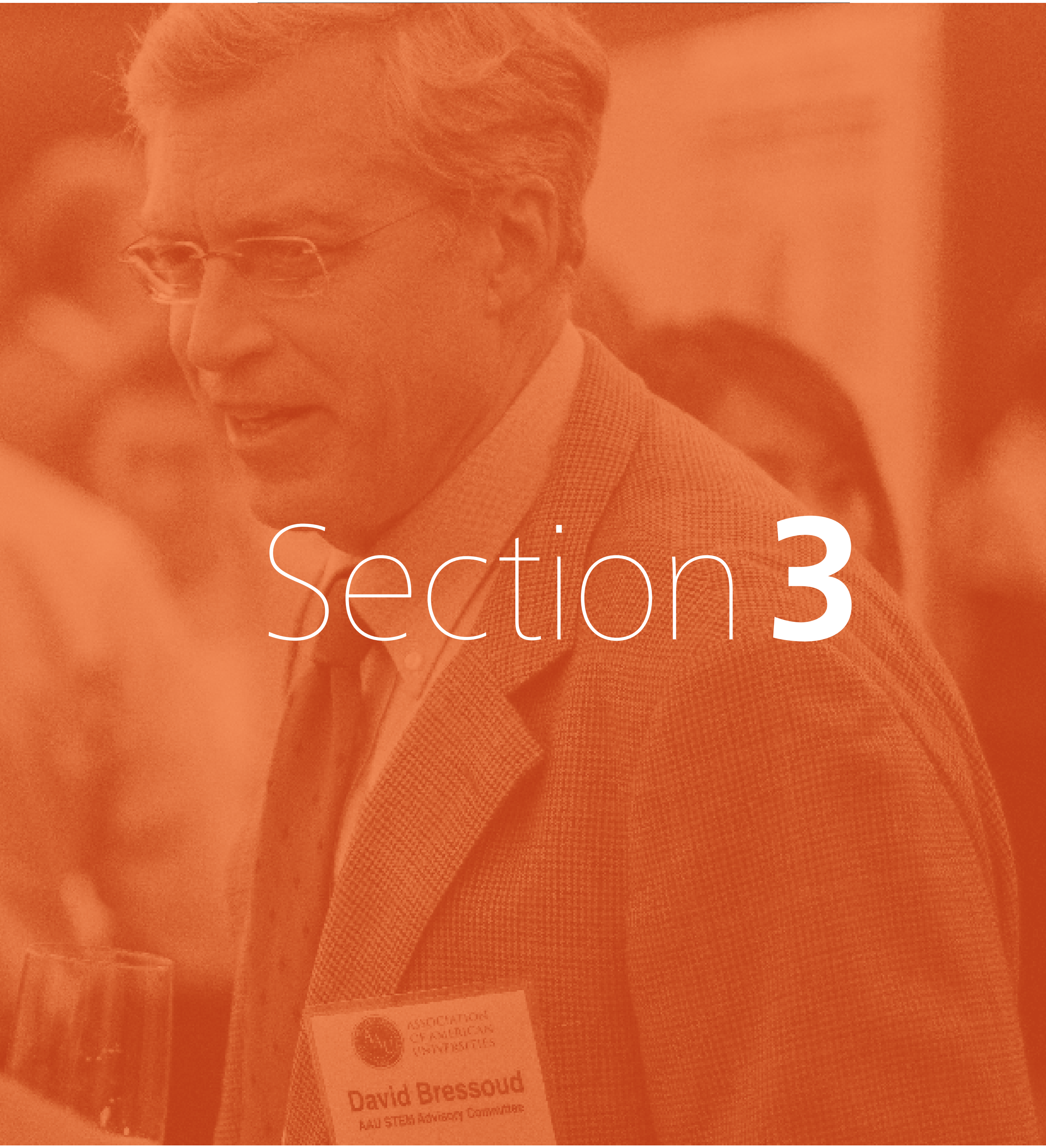
Burd, G. D., Novodvorsky, I., Tomanek, D., & Varma-Nelson, P. (2015). Improving teaching quality through peer review of teaching. In *Searching for Better Approaches: Effective Evaluation of Teaching and Learning in STEM* (pp. 47-58). Tucson, AZ: Research Corporation for Science Advancement. Retrieved from http://rescorp.org/gdresources/publications/effectivebook.pdf

Fisher, B. A., & Frey, R. F. (2015). Using documentary tools to foster the practice of scholarly teaching. *National Teaching and Learning Forum*, *24*(2), 4-6. http://dx.doi.org/10.1002/ntlf.30016

Frey, R. F., Fisher, B. A., Solomon, E. D., Leonard, D. A., Mutambuki, J. M., Cohen, C. A., Luo, J., Pondugula, S., & Frey, R. F. (2016). A visual approach to helping instructors integrate, document, and refine active learning. *Journal of College Science Teaching*, *45*(5), 20-26. Retrieved from http://www.nsta.org/store/product_detail.aspx?id=10.2505/4/jcst16_045_05_20

Solomon, E. D., Repice, M. D., Mutambuki, J. M., Leonard, D. A., Cohen, C. A., Luo, J., & Frey, R. F. (in review). A mixed method investigation of clicker implementation styles in STEM. *CBE-Life Sciences Education.* Manuscript submitted August 2017.

Section 3

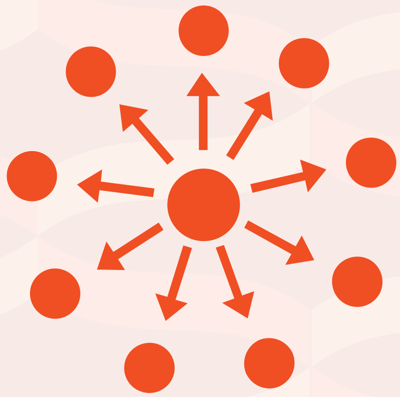

ASSOCIATION OF AMERICAN UNIVERSITIES
David Bressoud
AAU STEM Advisory Committee

NETWORK MEMBERSHIP

450+

AAU faculty members and institutional leaders

NETWORK GOAL



To spread innovative practices in under-graduate STEM education across AAU institutions.

JOIN THE NETWORK

All AAU members are invited to engage in the initiative.

AAU STEM Network

Since the start of its Undergraduate STEM Education Initiative, AAU's objective has been to include as many member universities as possible in activities that improve undergraduate STEM teaching and learning.

The high levels of interest in the Initiative — for example, AAU received concept papers from 31 universities to become project sites, but had the ability to seed-fund only eight — revealed the potential for a great deal of action. To further leverage the national impact of the Initiative, AAU believed that all member institutions should have the opportunity to engage. Moreover, other national examples demonstrate the effectiveness of networks and learning communities in spreading innovative practices in STEM education.

At the time of evaluating concept papers and selecting project sites, AAU took steps to encourage all member universities to continue to participate in the Initiative. First, AAU developed a transparent evaluation process for concept papers, and took care to ensure the project sites selected represented the diversity of the AAU membership in terms of institutional characteristics and the range of topics addressed by the projects. Second, before finalizing the selection of project sites, AAU announced the formation of a network and a network workshop to which all institutions were invited.

The AAU STEM Network is intended to be a collaborative network that helps to support and link AAU institutions grappling with similar challenges and barriers in reforming and improving STEM teaching and learning for undergraduate students. The network provides a forum to facilitate ongoing interaction and exchange of information and ideas, as well as to cultivate relationships among those leading reform efforts on different campuses. Network members share best practices and lessons learned, have access to resources, and can engage with those leading reform efforts focused on strengthening undergraduate STEM education. The network includes the primary point of contact for each campus but also includes others with various roles on campus, including administrators, faculty members, postdocs, and students.

The network provides a forum to facilitate ongoing interaction and exchange of information and ideas, as well as to cultivate relationships among those leading reform efforts on different campuses.

As of 2017, 55 AAU member universities have participated in the Initiative with more than 450 unique faculty members and institutional leaders. AAU has hosted three STEM network conferences and a fourth conference is planned for Fall, 2017. These conferences have given attendees opportunities to showcase their work and learn about the work of others, discuss common themes and challenges, and build relationships across campus roles and institutions.

To support a greater number of AAU campuses, AAU will award two rounds of twelve institutional mini-grants for intra- or inter-institutional work aimed at improving undergraduate teaching of introductory STEM courses. The intent of these mini-grants is to build upon and advance prior institutional commitments and newly established efforts aimed at sustained institutional change in undergraduate STEM teaching. Universities selected will receive $10,000 annually for a two-year grant period totaling $20,000 to support intra- or inter-institutional coordination of undergraduate STEM education reform. In addition, AAU will host a workshop for all mini-grant recipients and fund a campus visit by the AAU STEM Initiative project team to help leverage and highlight campus efforts.

The first cohort of mini-grants was awarded in January 2017 and went to California Institute of Technology; Cornell University; Iowa State University; Massachusetts Institute of Technology; McGill University; The University of Texas at Austin; University of California, Irvine; University of California, Los Angeles; The University of Kansas; University of Missouri, Columbia; University of Virginia; and Yale University.

AAU has learned through its Initiative that grants awarded by AAU to member institutions can have powerful symbolic implications on a campus that can help it to facilitate change. By providing institutions with even modest funds, department-based efforts become an institutional priority, and individuals leading these efforts have a lever to obtain additional institutional resources.

AAU universities are engaged in multiple innovative efforts to improve undergraduate education to help all students succeed. Several similar efforts are underway across the AAU STEM Network. AAU has observed:

- Department- and college-wide innovations to undergraduate teaching are recognized as institutional priorities.
- Data infrastructures and analytics are being capitalized on to improve student learning.
- Teaching and learning centers are being redesigned to support departmental reforms.
- Departments are hiring educational experts to provide leadership for systemic improvement to undergraduate STEM courses.
- Learning spaces are being developed and re-engineered to support evidence-based pedagogy.
- Universities are addressing the critical challenge of improving the evaluation of faculty teaching.

The following STEM Network Highlights feature innovate work occurring across the network. Visit aau.edu/STEM to learn more about AAU universities' work in STEM education. ■

STEM NETWORK HIGHLIGHT

Yale University Center for Teaching and Learning

Yale University established its Center for Teaching and Learning (CTL) in 2014 to support students, postdocs, and faculty across the campus to realize President Salovey's goal "to be the research institution most committed to teaching and learning." This new Center integrated various teaching, tutoring, writing and technology-enabled learning programs that were previously distributed across the university. The Center offers course design workshops and classroom observations, technology workshops, seminars on diversity and inclusion, writing support, science and quantitative reasoning tutoring, and global online learning initiatives via Coursera. The CTL promotes evidence-based teaching methods for all university instructors, including faculty and graduate teaching fellows. The Center also supports student learning and provides opportunities for students and postdoctoral scholars throughout the University to develop as teachers, mentors and leaders.

Staff members at the Center routinely assist members of the Yale community with course design, section planning, effective use of technology, assignment development, mid-semester classroom observations and feedback, interpreting student evaluations, and addressing challenges in the classroom.

The Center makes teaching and learning more public by promoting conversation and collaboration among all the stakeholders, and by sharing select university teaching initiatives with a global audience. Evidence-based decisions about teaching and learning are valued, and the Center helps faculty, departments, and programs design meaningful ways to measure impacts.

The Center reports to the Deputy Provost for Teaching and Learning and is led by professional staff members. Center staff collaborate with many other Yale and external organizations to fulfill the unit's mission.

STEM NETWORK HIGHLIGHT

Lecturers with the Potential for Security of Employment

Lecturer with the Potential for Security of Employment (LPSOE) and Lecturer with Security of Employment (LSOE) are designations used by the University of California for faculty members appointed to help meet the long-term instructional needs of the university that cannot be best fulfilled by an appointee in the Professor (Ladder Rank) series.

LPSOEs and LSOEs are expected to contribute excellent teaching, and play a leadership role in teaching in their departments and disciplines. They also have leadership responsibilities that transcend teaching, including as facilitators and initiators of instructional development, curriculum design, course structure, teaching methods, new technologies, and coordination of a spectrum of teaching activities.

LPSOEs are equivalent in level to assistant professors. They have a probationary period and may be appointed in the series for no more than eight years. They receive appraisals and are considered for promotion to LSOE on the same timelines as assistant professors. LSOEs are equivalent in level to associate professor, and “security of employment” is analogous to tenure. The title “Senior Lecturer” may be assigned to an appointee who provides services of exceptional value and whose excellent teaching and professional accomplishments have made him/her a recognized leader in his or her professional field and/or in education. The Senior LSOE is equivalent in level to full professor.

Appointees in the LPSOE/LSOE series are reviewed for performance using four criteria:

1. Teaching of truly exceptional quality,
2. Professional achievement and activity: an appointee in the LSOE series is expected to maintain currency in the profession and pedagogy,
3. University and public service, and
4. Educational leadership beyond the campus and contributions to instruction related activities (i.e., conducting TA training, supervision of student affairs, development of instructional materials/multimedia).

STEM NETWORK HIGHLIGHT

University of Michigan Digital Innovation Greenhouse

The University of Michigan's Digital Innovation Greenhouse (DIG) exists to design and develop innovative software tools that support the improvement of education through personalization at scale. "Personalization at scale" refers to taking innovations that personalize education, tailoring them to individual student needs and increasing engagement, and scaling these up so that all students can have access to them. Digital enterprises too often lack the resources to fully grow from early innovation to widespread adoption, and DIG exists to help efforts overcome the "valley of death."

DIG works with user communities to grow tools to maturity, and establishes a pathway to scale through collaboration across U-M's digital ecosystem. With a team (including faculty, staff, and student fellows) of developers, designers, behavioral scientists, and data scientists, DIG helps translate digital engagement tools from innovation to infrastructure.

One of DIG's main projects is developing Academic Reporting Tools (ART 2.0). ART 2.0 is a data visualization tool that will assist decision makers in accessing and analyzing course and academic program data to help administration, faculty, and students make more informed decisions. ART 2.0 will optimize instructional practices for faculty and answer questions such as "what majors are my students pursuing?" while also structuring the learning process for students through an interactive platform that answers questions such as "what courses have most of the students in this course already completed?" By allowing students and faculty alike to access data on courses and majors from past academic terms, ART 2.0 is fostering a community that allows for data driven information to lead towards better decision making. Other projects DIG is current engaged in include:

- ECoach – a way to provide students with personalized assistance in large classes, which has already assisted over 15,000 students at U-M.
- GradeCraft – using gaming to enhance student motivation and learning.
- M-Write - writing-to-learn pedagogies that ask students them to explain what they know, interact with one another through peer review, and learn through a revision process.

DIG has also worked on learning tools focused on sustainability cases, interactive role-playing simulations, and a library of problems for self-testing, as well as developing an early warning system for advisors that flags when students are struggling in their courses.

STEM NETWORK HIGHLIGHT

Cornell University Arts & Sciences Active Learning Initiative

One way in which Cornell University has empowered departments to improve teaching and learning across dimensions of their undergraduate curriculum is through the Active Learning Initiative (ALI). ALI allows departments to submit proposals and receive grant funding from the institution to "encourage and facilitate high-impact learning practices, technology enhanced learning, and a culture of educational excellence at the departmental and college levels."

ALI's initial efforts began five years ago with the conversion of four large course sequences in physics and biology, changes that have led to increased student learning gains, especially from students who had been receiving poor grades. Earlier in 2017, the university announced a $2.7 million expansion of the initiative, funded by a gift from two alumni.

One of the two donors, Alex Hanson, noted that donors and volunteers want to make a positive impact, and "Laura [the other donor] and I have been impressed with the game-changing quantitative and qualitative results so far [of the ALI]," he said. "The College has demonstrated both a large treatment effect and a statistically significant improvement."

This second iteration involves six new projects in the Departments of Music, Classics, Economics, Mathematics, Physics, and Sociology. These new projects will impact thousands of students each year.

For example, the mathematics project will change how courses are taught that reach students at critical transition points in their mathematical development. Goals for the project include increasing student confidence in their own mathematical abilities and improving student perception of mathematics as an inquiry-based discipline. The physics project will focus on rethinking how labs work to develop students' scientific reasoning, critical thinking, and experimentation skills.

According to Peter Lepage, Director of Education Innovation and Goldwin Smith Professor of Physics, "The projects chosen outline clear ideas that will improve student learning in ways that can be measured, and therefore propagated to other courses and departments. And they involve teams of faculty that will generate new energy and thought around pedagogy in the departments and the rest of the college."

STEM NETWORK HIGHLIGHT

University of Kansas Department Evaluation of Faculty Teaching Rubric

The University of Kansas (KU) requires that evaluation of faculty teaching — including information from the instructor, students, and peers — be considered for promotion and tenure. However, traditionally the quality of this information has been highly variable and reviewers may struggle to make sense of it. In practice, many evaluations have prioritized a narrow dimension of teaching activity (the behavior of the instructor in the classroom) and a limited source of evidence (student evaluations). To address these shortcomings, the Center for Teaching Excellence at KU recently developed a rubric for department-level evaluation of faculty teaching.

The goal of the rubric is to help departmental committees integrate information from the faculty member being evaluated, their peers, and their students to create a more holistic view of the faculty member's teaching contributions. The rubric identifies seven dimensions of teaching practice that address contributions to both individual courses and the department's curriculum:

1. Goals, content, and alignment
2. Teaching practices
3. Achievement of learning outcomes
4. Classroom climate and student perceptions
5. Reflection and iterative growth
6. Mentoring and advising, and
7. Involvement in teaching service, scholarship, or community.

For each of these categories, the rubric provides both guiding questions and defined expectations. The rubric can also be used to guide a constructive peer-review process, reflection, and iterative improvement. To ensure applicability across disciplines, the rubric does not weigh or place focus on any particular element or require a particular type of evidence to be used. Departments are encouraged to modify the rubric and use it to build consensus about the dimensions, the questions and the criteria.

Providing a rubric to structure the evaluation of faculty members' teaching increases the visibility of all dimensions of teaching, clarifies faculty teaching expectations, enables quick identification of strengths and areas for improvement, and brings consistency across evaluations and over time.

The implementation strategy for the rubric included discussions with department chairs and KU Center for Teaching Excellence department ambassadors in advance of its release to increase the probability of broad buy-in. The rubric was piloted during the 2016–2017 academic year as a guide for peer review of teaching, promotion and tenure, and third-year reviews.

STEM NETWORK HIGHLIGHT

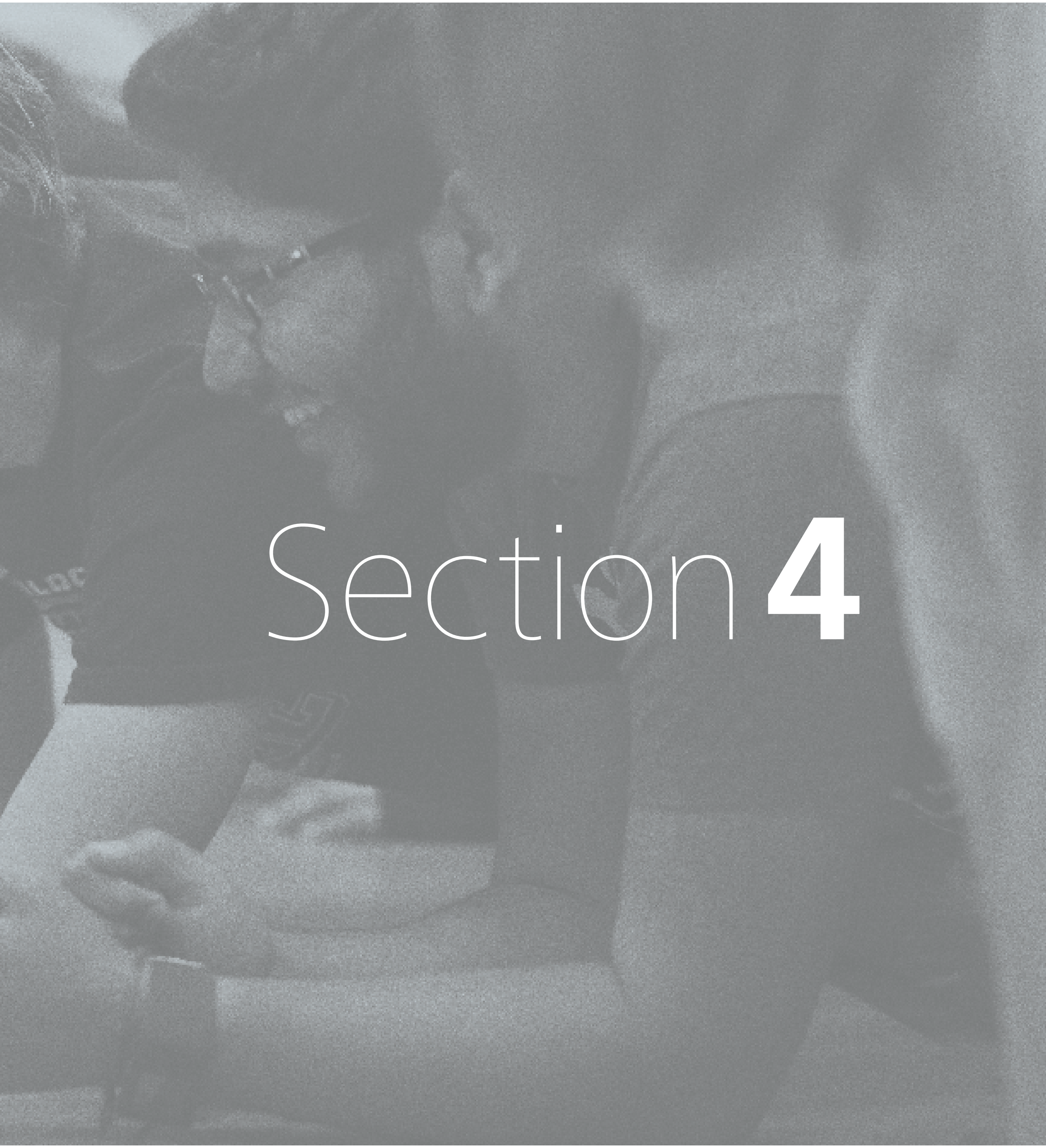
Learning Analytics Fellows Program

In 2015, Indiana University Bloomington (IUB) initiated a Learning Analytics Fellows Program (Fellows), a multidisciplinary Community of Transformation made up of faculty members from across the Bloomington Campus. Faculty members engage in scholarly research that uses learning analytics to analyze student success in their courses, curriculum, and programs to advance IUB's strategic plan and its commitment to improved student success. Participating faculty members gain the knowledge and skills necessary to use learning analytics to make data-driven decisions about student success at the course, program, and university levels.

Since 2015, twenty-eight faculty members:

- participated from 11 different programs
- conducted 29 unique research projects
- studied 150,000 individual students
- analyzed 3.2 million student records

Early adoption by Fellows to use analytical data, and their ongoing research about student success, will continue to contribute to institutional efforts to create a culture at IUB that values data-driven decision making, with the ultimate goal of improving success for all students.



Section 4

Movement Toward Institutional Change

At AAU Universities

The following recommendations draw primarily from AAU's cross-institutional portrait of successful undergraduate STEM educational reforms. In addition to the AAU Framework, several factors seemed to support – or when absent work against – adopting evidenced-based pedagogies in introductory STEM courses. The following key elements indicated movement toward systemic change in reforming undergraduate STEM education.

Shift from individual to collective responsibility for curricula and instruction.

- A department and its faculty members must recognize and acknowledge their collective responsibility and ownership to improve the effectiveness of the department's introductory/foundational courses.
- Decisions about what fundamental concepts students need to learn in introductory courses should no longer be left solely to the discretion of the individual faculty member teaching the course for a semester. Instead, these decisions must be made collectively by an entire department.
- Departments must actively promote the use of evidence-based active-learning strategies in foundational courses and work jointly with faculty members to develop uniform ways to assess student learning in these courses.

Hire educational experts within departments to bolster reforms.

- Educational experts should be formally embedded into the departments to support all faculty members in the adoption and use of evidence-based pedagogy and proven effective instructional practices.
- Individuals in these roles should provide educational leadership to the department to help achieve desired reform through redesigning courses, co-teaching courses with other faculty members, taking on the responsibility for

departmental-wide educational improvement, and producing scholarship for the broader higher education community based on the evaluation of reformed courses.

- Embedded teaching experts within a department should be expected to engage in efforts with other STEM departments across the institution to better coordinate cross-disciplinary learning objectives, to share best practices, and to achieve broader institution-wide systemic STEM teaching reforms.
- Acceptance, support, and respect for the role of individuals with instructional expertise by departmental leadership and tenure-track faculty members is an essential element for long-lasting change. Given that institutional policies at research universities usually state that education is of equal value to research, faculty members and staff embedded within STEM departments with specific expertise in teaching should not be treated as 'second class citizens.'

Reorganize institutional structures to support departmental reform efforts.

- Symbolically and practically, establishing and maintaining organizations that support STEM educational reforms is an essential element of eventual institutionalization. The work of various administrative units, such as Centers for Teaching and Learning, must be reoriented to better align with department based instructional improvement efforts and support the work of embedded teaching professionals within the departments.
- At some institutions, additional within- and between-department structures should be created to support STEM educational reforms, particularly those that can help faculty members to evaluate, assess, and continually improve the effectiveness of their teaching.

Harness institution-wide data to support student learning.

- Research universities can greatly facilitate STEM education improvement by supporting the development and use of institution-wide data and analytical tools on student instruction and learning outcomes. It is critical that data that is collected by the institution be compiled and shared with departments in ways that help them and their faculty members to continually enhance the quality of their STEM instruction.
- Universities should develop efficient tools to assist faculty members in their teaching and to assist administrators in monitoring student progress.

Develop new institutional business and financial models to promote sustained improvement of undergraduate STEM education.

- Undergraduate STEM education improvement at research universities *cannot* effectively be sustained based upon the same 'from one grant to the next' model that has been used to support research. Clearly an institutional commitment must be made.
- Funds will be required to hire the types of personnel best suited to enhance the quality of undergraduate STEM education while understanding these hires must fit into a research university setting.
- Additional learning spaces must be created to support active-learning techniques accompanied by support for faculty professional development around the effective use of the enhanced spaces.

- Institutional leadership should find innovative ways to include improving the quality of undergraduate teaching in their major fundraising campaigns. They should also seek funds from industrial sponsors to endow "Chairs for Educational Excellence" within STEM departments.

Better manage the simultaneous pursuit of high quality teaching and research.

- The development and use of more effective ways to evaluate teaching in the faculty reward structures will be required to institutionalize STEM educational reforms.
- Alternatives beyond the sole use of student evaluations/ratings must be developed and employed in evaluating the quality and effectiveness of faculty teaching.
- Institutions and departments need to modify their hiring practices to make clear that they have an expectation of excellence in teaching in addition to excellence in research.

Leverage AAU to advance educational reforms and institutional change.

- Situating the eight project sites within the larger AAU STEM Network was an effective way to encourage local reforms especially when peers from similar departments and types of institutions are doing similar activities on their campuses.
- By AAU providing institutions with even modest funds, department-based efforts become an institutional priority, and individuals leading these efforts have a lever to obtain additional institutional resources.
- AAU involvement has symbolic implications that can help campuses achieve cultural and institutional change by providing legitimacy to STEM education reform efforts.

At AAU

In addition to AAU members and non-member research universities taking these steps, if long term systemic reform in undergraduate STEM education is to be achieved, it will also be important that AAU itself sustain the commitment it has made to supporting educational improvement at the undergraduate level. To help maintain the momentum for reform that has been generated by the Initiative, AAU leadership has already committed to extend the initial five-year effort indefinitely by integrating continued support for undergraduate STEM education reform and improvement into its ongoing staffing structure and portfolio of work. Additionally, AAU will continue to explore how lessons learned to from the Initiative can be applied to improving undergraduate teaching in other non-STEM disciplines and how AAU, as an association, can continue to promote excellence in undergraduate education. ■

In collaboration with Adrianna Kezar, Professor Rossier School of Education and Co-Director, Pullias Center for Higher Education at the University of Southern California, AAU examined **how a national higher education association can in fact encourage and help create educational change at its member institutions.**

The National Science Foundation study, "Scaling Undergraduate STEM Education Reforms at AAU Institutions," used the AAU Undergraduate STEM Education Initiative as a real-time, field-based innovation to examine the unique role AAU can play as compared to any other organization nationally to achieve scale of evidence based teaching practices. The overarching objective is to determine *how the AAU STEM Initiative achieves scale of reforming undergraduate STEM teaching and learning. The study also examined the distributed leadership role of AAU and its influence as a result of being a highly-esteemed organization in higher education.*

The study involved document analysis, observations, and interviews. In total, over 10,000 pages of documents were reviewed to understand the Initiative and observations were conducted over two and half years. Four groups were interviewed: 1) AAU STEM Initiative key leaders and personnel; 2) faculty members and administrators at the AAU STEM Project Sites; 3) faculty members and administrators active in the AAU STEM Network; and 4) collaborators from outside organizations that have worked with AAU on the Initiative. In total, the study included 104 interviews. The following key themes emerged from the study:

Assess your strengths and assets as an organization. One of the most important lessons derived from this study is the importance of organizations engaged in change processes to start by assessing their strengths to help devise the best and most strategic approach. For AAU, these strengths included their ability: a) to influence leaders such as president and provosts and other prestigious and influential organizations within the higher education sector; b) to create and leverage networks; c) to define overarching logics or value systems for the enterprise; and d) to work across various key stakeholders of the higher education system.

Use a systems approach to scale change. Every organization is able to work at different levels of a system. Some organizations are well-positioned to help with creating change at a specific level of a system, while some organizations can work across multiple parts of the system. Research has shown that more levels of the systems that are impacted, the more likely changes are to scale and be sustained. AAU was an organization that could work at multiple levels and utilized this capability. One of the beneficial outcomes of the AAU initiative was thinking about aligning different efforts within the overall landscape of improving undergraduate STEM education. Organizations should establish where they can work best within the overall system and strategically apply their efforts.

Use multiple change theories for maximum impact. In projects that involve multiple stakeholders and complex motivations and issues, using multiple theories of action to scale change can be extremely valuable. Leaders in AAU adopted a multi theory approach to the change process that benefited their trajectory forward and efficacy. It is all too common for change efforts to adopt a more simplistic approach to change and AAU's deployment of various theories of action increased their chances of success. Embedding strategies which can be used in multi-faceted ways as AAU did is also a very efficient way to use time and resources, finite factors that are generally in low supply.

Understand and consider influence strategies. Influence is generally an implicit strategy and not one that organizations conduct strategic planning around - even though it is an important lever for change. This study was able to provide concrete descriptions for what influence can look like within higher education setting. AAU's most important change strategy was deploying its influence as a prestige organization to garner the attention of leaders and to motivate change. Every organization has the ability to influence some set up of groups of individuals and consideration of the most effective influence strategies is particularly important for a strategic approach.

Carefully evaluate framing, messaging, and language used to communicate change. While there is a great deal of attention to language as it relates to visions articulated in change processes at the single institutional level, the process of articulating new "institutional logics" that guide more macro change processes have not been articulated in the higher education change literature. Just as individual institutions must carefully craft a vision around change for institutional strategic planning processes, scaling efforts must also articulate a "common agenda" and even more importantly a compelling new set of logics to undergird institutional action across the sector. AAU successfully created a strong message that "AAU institutions need to be as excellent in teaching as they are in research," which was a very compelling message to stakeholders. Organizations attempting to scale change should very carefully evaluate the logics they are developing and the language used articulate the new logic.

Use networks to scale change. Organizations often organically allow networks to develop and may not intentionally plan how networks can be used and connected to scale change. AAU strategically considered and developed networks. Organizations can use the lessons from this study to help define and implement networks for scaling change.

Create distributed leadership for improving STEM education. The literature on scale suggests that leadership throughout the system is critical for scaling changes. Distributed leadership draws on leadership throughout the system and does not make distinctions between leaders in formal positions of authority versus informal leaders in terms of their value and importance for creating change. Leaders at different levels have insights into particular issues related to the change content as well as process. AAU partially played this role through its conveying power in that it brought together leadership from across the system. Reform efforts would benefit from an organization facilitating the development of leaders at these multiple levels in support of improving undergraduate STEM education.

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