Association of American Universities
Five-Year Initiative for Improving Undergraduate STEM Education

DISCUSSION DRAFT

Updated October 14, 2011

Introduction

The Association of American Universities (AAU) is a nonprofit organization of 59 U.S. and two Canadian leading research universities. AAU's work focuses on issues that are important to research-intensive universities, including undergraduate education. Improving science, technology, engineering, and mathematics (STEM) education for undergraduates is a long-term challenge and a national need, and many AAU institutions are among those at the forefront of addressing this need.

Improving undergraduate STEM education is not a new issue, but it has taken on new resonance in recent years as the nation's need for more STEM graduates has increased. Along with the publication of several high-level reports that have identified deficiencies and potential solutions, new scholarship on teaching and learning has led to the development of techniques that have been demonstrated to be more engaging and more effective at helping students learn.

Building on this previous work, AAU is embarking on a new, five-year initiative to improve undergraduate STEM education.

We will work with our institutions and other organizations to develop an effective analytical framework for assessing and improving the quality of STEM teaching and learning, particularly in the first two years of college. Using that framework, we will partner with a set of AAU-member institutions to implement the framework through a demonstration project in which we measure improvements in teaching, learning, and STEM retention and degree completion. We also will work with federal agencies, other funders, the business community, and our institutions to develop incentives for faculty members to teach in ways that have been proven to be effective.

In advance of launching the initiative, we have surveyed our institutions about their specific policies and activities related to improving undergraduate STEM education, and we have compiled a list of campus programs designed to increase retention of undergraduates in STEM majors. We will use these and other examples to develop a best-practices guide for institutions.

Our goal is to work together in a coordinated fashion with higher education associations, individual universities, disciplinary societies, federal agencies, and the business community to bring about improvements that help our students, and our nation, meet the challenges of tomorrow.

The Problem

Improving undergraduate teaching is integral to meeting the pressing national need for more STEM majors. In the United States, the STEM[1] fields form the core of the post-World War II university-government partnership. These fields have been critical to generating the new ideas, companies, and industries that have driven our nation's economic competitiveness. The importance of STEM will only grow in the future. According to a recent report from the U.S. Department of Commerce, STEM occupations are projected to grow by 17 percent from 2008 to 2018, compared to 9.8 percent growth for non-STEM occupations.

The STEM workforce depends upon our system of higher education. More than two-thirds of STEM workers have at least a college degree, compared to less than one-third of non-STEM workers. STEM workers earn 26 percent more than their non-STEM counterparts, and STEM degree holders earn more than non-STEM degree holders, whether they work in STEM occupations or not. Yet, according to the Organization for Economic Cooperation and Development, in 2009 the U.S. ranked 27th out of 29 developed countries in the percentage of students who earned bachelor's degrees in science or engineering. Figure 1 shows how the U.S. compares to selected other nations.

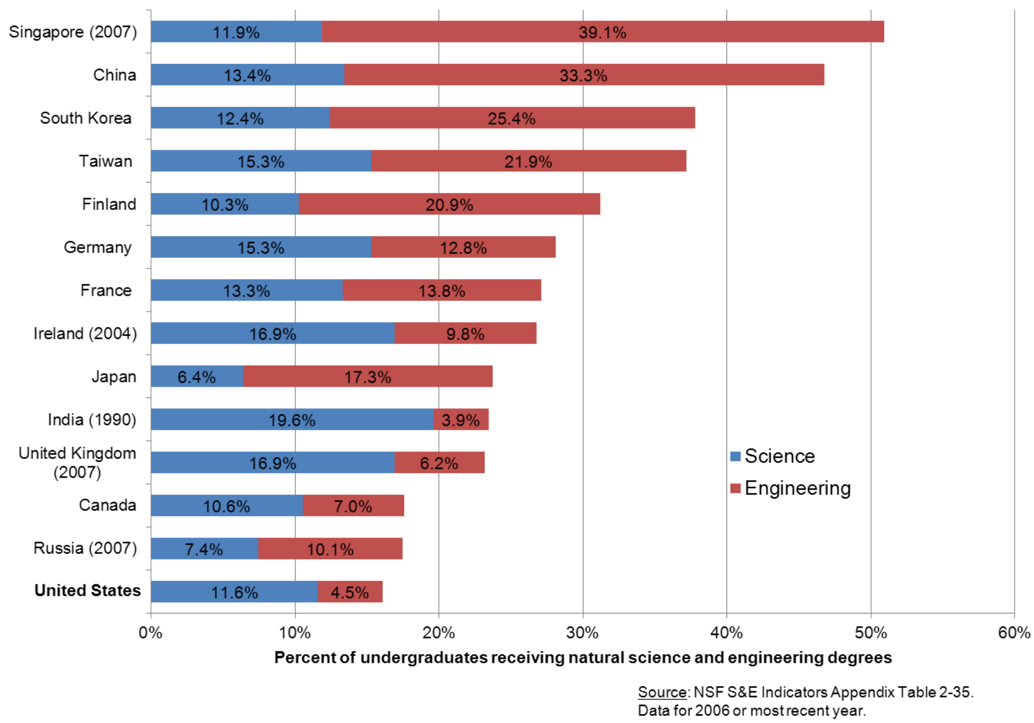
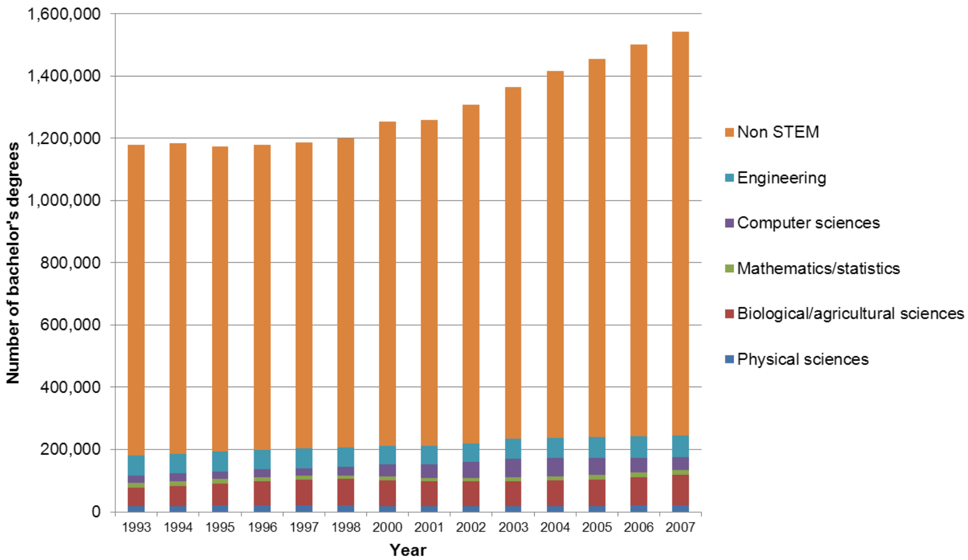


Figure 1

According to National Science Foundation (NSF) data, university enrollments continue to increase, as do numbers of bachelor's degrees 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 (Figure 2).

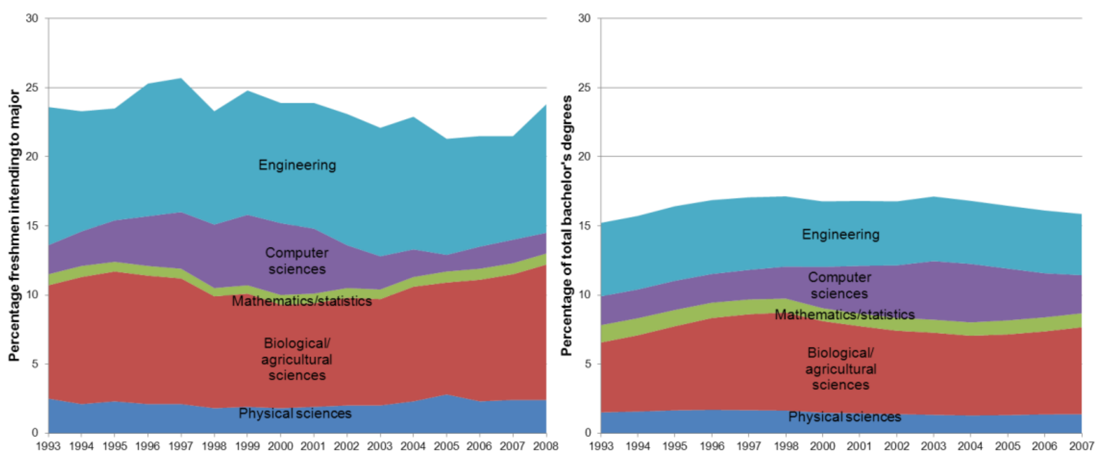
[1] We define STEM to include biological and agricultural sciences; physical sciences (physics, chemistry, astronomy, earth, oceanic and atmospheric science); engineering; and mathematics, statistics, and computer sciences.



Source: NSF S&E Indicators 2010, Appendix Tables 2-6 and 2-12

Figure 2

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. NSF data allow a comparison of the STEM disciplines freshmen intend to major in with the distribution by discipline of actual degrees awarded (Figure 3), showing in more detail the decline from percent of intended majors to percent of degrees awarded.



Source: NSF S&E Indicators 2010, Appendix Tables 2-6 and 2-12

Figure 3

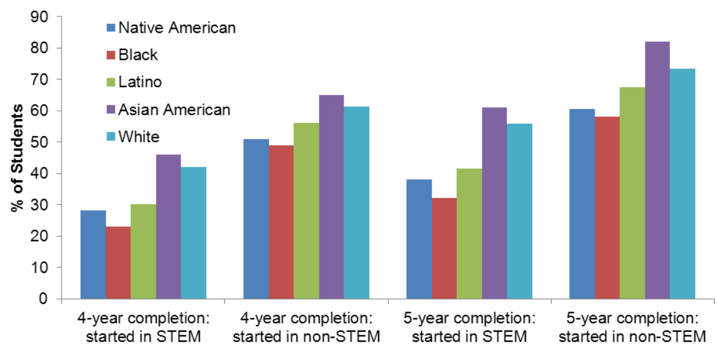
Many students who intend to major in a STEM field do not complete their degrees, or wind up earning degrees in non-STEM disciplines. According to the 2005 Survey of the American Freshman (as reported by the House Science Committee), **half of all students who begin in the physical or biological sciences and 60 percent of those in mathematics will drop out of these fields by their senior year, compared with a 30 percent drop-out rate in the humanities and social sciences.**

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. This pattern is borne out by more recent data. The [Higher Education Research Institute] (HERI) reports 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. For students who entered college in fall of 2004 intending to major in a STEM field, HERI calculates the number of students by race who completed STEM bachelor's degrees within four and five years (Table 1).

Table 1

Race	4-year completion	5-year completion
Native American	14.0%	18.8%
Black	13.2%	18.4%
Latino	15.9%	22.1%
Asian American	32.4%	42.0%
White	24.5%	33.0%

The HERI analysis also shows 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 (Figure 4).



Source: HERI, 2010.

Figure 4

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 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, as did 73 percent of those who did not leave STEM. About half of the students who left STEM also cited "curriculum overloaded, fast pace overwhelming" and "non-[STEM] major offers better education\more interest" as factors in their departure. 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 is 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.**

Improving teaching will require cultural change. There is a large and active scholarship on improving teaching STEM to undergraduates, and techniques have been developed that have been demonstrated to be more engaging to students and more effective at helping them learn. The challenge, according to Noah Finkelstein, an Associate Professor at the University of Colorado, is not figuring out what works. **The challenge is to persuade faculty members, who want to be good teachers, to implement these practices in their own classes. This, as has been pointed out by many, will require cultural change at universities.**

We must understand the aspects of university culture that may make the diffusion and adoption of new modes of teaching by faculty difficult if we are to effect cultural change. The university-government partnership is indeed a partnership, and the culture of research universities has been created and maintained by both partners. In particular, according to Robert Mathieu, "external [research] funding plays a major role in defining importance and legitimacy."

Research activity, which is relatively easy to measure (through research funding and publications, among other metrics) and reward, often takes precedence over pedagogy. A recent survey of university faculty members by *Nature* highlights the ambivalence about the relationship between teaching and research. Faculty members believe that improving the quality of lectures and teaching is an important potential solution to the problem of improving undergraduate STEM education. Indeed, they ranked this factor the second most important of five. Improving secondary school science education ranked slightly higher, but undergraduate teaching ranked higher than increasing the time students spend in well-resourced labs, decreasing class size, and reducing the cost of education. At the same time, the majority of faculty members consider themselves to be effective teachers. And when asked about the relative importance of teaching and research responsibilities to the future of science worldwide, only 7 percent of respondents considered teaching less important than research. However, when asked about filling a new faculty position requiring both teaching and research responsibilities, a plurality favored a star researcher with no significant teaching experience (Figure 5). Only 16 percent of respondents favored a superb teacher with no significant research experience.

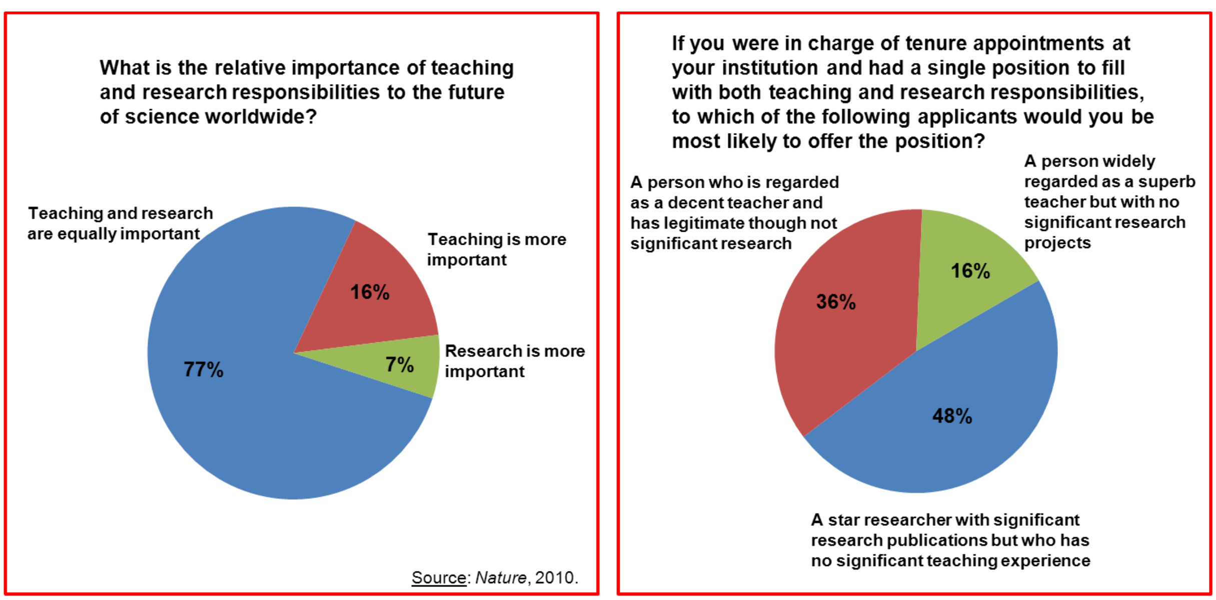


Figure 5

In addition to being asked about their own values, faculty members were also asked about their institution's values. The plurality (41 percent) felt that their institutions valued research more than education. According to the *Nature* report: "…many scientists have concluded that research and teaching are, in fact, set against each other in a `zero-sum' game—a game in which success in one area is entirely at the expense of success in the other. And it is clear which side of the game scientists feel holds the greater rewards, both financial and social. As a result, scientists naturally align their decisions—about both themselves and others—to promote contributions at the bench over those in the classroom." The *Nature* report points out that both institutions and research agencies and other funders have roles to play in realigning these values.

As this discussion makes clear, the focus must be on encouraging faculty members to change their methods of teaching. It is perhaps an oversimplification to claim that *the* culture for faculty can be changed, because faculty members live in at least two cultures: an institutional culture and a disciplinary culture. Faculty members are influenced by their roles both as members of a university community and as practitioners in their field.

Faculty members' behavior can be influenced through at least three (not mutually exclusive) mechanisms: policy, funding, and mores and norms. For example, universities and individual colleges, schools and departments, along with the federal government, set policy that most directly affects faculty members. Government, industry, and foundations are the most influential funders of research performed by faculty. And faculty mores and norms are heavily influenced by discipline, through departments and scientific societies, as well as by the culture of the institution itself.

An appendix to this document provides a list of strategies for changing institutional and disciplinary cultures to assist faculty members in utilizing effective teaching techniques. Examples and resources already exist for most of these ideas.

AAU's Initiative

To effect change in undergraduate STEM teaching, researchers have identified four strategies: 1) disseminating curricula and pedagogy; 2) developing reflective teachers (defined as those who use their own knowledge/experience/skill to improve their instructional practices); 3) enacting policy (including incentives and quality assurance measures); and 4) developing shared visions (including departmental-level collaboration and institutional-level actions). To be successful at changing teaching, especially in classes taken during the first two years of college, AAU's effort must include aspects of all of these.

AAU can help address the barriers to improving STEM teaching because the association has relationships with many of the organizations working to improve undergraduate education. As a national association of leading research universities, we also are in a position to help convene and focus the attention of campus administrators, as well as to facilitate conversations among administrators, policymakers, and funders. Our institutions are an integral part of the university-government partnership. In 2008, our institutions received more than half of all federally funded research provided to colleges and universities. In 2006, our institutions awarded nearly a quarter of a million undergraduate degrees, more than 16 percent of the national total. AAU institutions award more than half of the nation's doctorates, including 54 percent in the life sciences, 61 percent in the physical sciences and mathematics, and 60 percent in engineering (for 2008). According to Mathieu, "in the United States, roughly 100 research universities produce 80 percent of all doctoral degrees, and the vast majority of the faculty members in the nearly 4,000 colleges and universities of the U.S. pass through these research universities." Thus, changes at our institutions can make a lasting impact over time.

As a first step, AAU is assembling a technical advisory committee composed of experts in undergraduate STEM teaching and learning. The technical advisory committee will assist AAU in developing and executing its initiative to achieve its goals. At this time, the following individuals have agreed to serve on the technical advisory committee:

- Peter Bruns, Vice President for Grants and Special Programs (retired), Howard Hughes Medical Institute (HHMI)
- James Fairweather, Mildred B. Erickson Distinguished Chair in Higher, Adult and Lifelong Education, Michigan State University
- Noah Finkelstein, Associate Professor of Physics Education Research, Department of Physics, University of Colorado at Boulder
- S. James Gates, Jr., John S. Toll Professor of Physics and Director, Center for String and Particle Theory, University of Maryland, College Park
- Jo Handelsman, Howard Hughes Medical Institute (HHMI) Professor, Frederick Phineas Rose Professor of Molecular, Cellular and Developmental Biology, Yale University
- Sylvia Hurtado, Professor and Director of the Higher Education Research Institute (HERI), University of California, Los Angeles
- Peter Lepage, Harold Tanner Dean of Arts and Sciences and Professor of Physics, Cornell University
- Kathy Mann Koepke, Director of Mathematics and Science Cognition and Learning, National Institutes of Health (NIH)
- Bassam Z. Shakhashiri, Professor of Chemistry, William T. Evjue Distinguished Chair for the Wisconsin Idea, University of Wisconsin-Madison, and 2011 President-Elect, American Chemical Society
- Candace Thille, Director, Open Learning Initiative (OLI), Carnegie Mellon University

Linda Slakey, Senior Staff Associate for the Directorate for Education and Human Resources at NSF, has agreed to be NSF liaison to the advisory committee.

AAU will work closely both with our own institutions and with other groups that are already engaged in complementary efforts, including:

- the Association of Public and Land-grant Universities (APLU), which has undertaken major efforts to expand the number and quality of K-12 STEM teachers and to redesign gateway courses at universities and community colleges using online learning tools,
- the Business-Higher Education Forum (BHEF), which has launched major initiatives to improve college readiness, access, and success and to address issues relating to STEM workforce needs,
- the Howard Hughes Medical Institute (HHMI), which is a major funder of efforts to improve undergraduate biology teaching and learning through its HHMI Professors Program and other initiatives,
- the President's Council of Advisors on Science and Technology (PCAST), which has formed a working group on these issues and is expected to release a major report with recommendations, and

- Various disciplinary societies, including the American Physical Society (APS), which has programs to help new faculty learn to implement more effective methods of teaching and assessment.

The main goals of AAU's Undergraduate STEM Education Initiative are:

Goal #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.

The Association of Public and Land-grant Universities (APLU) has designed an extensive analytic framework for STEM teacher preparation and development as part of its Science and Mathematics Teacher Imperative (SMTI). AAU's technical advisory committee can help us develop a process for creating a complementary framework for effective undergraduate STEM teaching.

Some important elements of an effective analytical framework for assessing and improving the quality of undergraduate STEM teaching and learning, particularly in the first two years of college, as drawn from the literature, might be:

- Developing learning goals—at the module, course, discipline, and institutional levels, and ensuring that these are linked in a coherent fashion and are measurable.
- Engaging students as active participants in learning—including the use of small group activities and other ways of allowing students to form learning communities.
  - Providing feedback to students in real-time.
  - Reducing time spent lecturing and increasing use of other instructional methods—including technologies such as clickers and online learning, in addition to other kinds of activities.
  - Allowing students to engage directly in scientific research—opportunities for research experience in the first two years may be especially important to retention, and such opportunities may exist both inside and outside the classroom.
  - Developing and utilizing assessment tools—these can be linked back to learning, and ultimately to student success, and can be important at the level of the individual instructor, department, institution, and discipline.
- Using scenarios and real-world examples to teach concepts and problem-solving skills.
- Applying appropriate research techniques to teaching ("scientific teaching")—if STEM faculty consciously inquire into the effectiveness of their own teaching, they can use the information they collect to further improve their teaching, allowing them to practice scholarship in the classroom. This is a core component of the activities of the Center for the Integration of Research, Teaching, and Learning (CIRTL), an NSF center for learning and teaching in higher education.
- Considering learning at levels other than the course—from individual learning goals to learning modules to series of courses and entire disciplinary and institutional curricula, courses should not be treated as isolated units, or as necessarily the most important units.

Goal #2: Create a demonstration program at a subset of AAU universities to implement the framework. Activities would include developing tools to survey and assess: a) the quality of teaching and learning in STEM classes, b) the extent to which effective teaching methods are being used by academic departments, and c) the effects of improved teaching on retention of STEM majors and completion of STEM degrees.

While assessment is a critical piece of efforts to improve undergraduate education, it is an area where efforts can get bogged down or lose focus. For that reason, it may be helpful to think about assessment in tiered fashion:

- First, are faculty members using improved teaching techniques in their classrooms? How many classes, departments, and institutions are using these techniques, and how much are they using them? Carl Wieman, Associate Director for Science at the White House Office of Science and Technology Policy and a leader in improving science education, has developed a survey device to assess this. A number of discipline-specific surveys have also been conducted (e.g. for geosciences and physics).
- Second, is use of these techniques truly leading to improved learning? The literature suggests it will, but faculty members can directly judge this themselves by using a number of assessment tools.
- Third, we must measure STEM retention and completion rates. Some data already exist (such as those reviewed above), but better and more department- and institution-specific data should be collected. This may include not just retention and completion rates but also longitudinal surveys of students to understand why they do or do not stay in STEM fields (to update the work of Seymour and Hewitt).
- Finally, how does enhanced teaching and learning improve STEM retention and completion?

To help oversee the demonstration program and guide and provide leadership to its undergraduate STEM initiative, AAU will create a broad-based task force. This new task force will be critical to establishing the demonstration program, and will help ensure that the institutions involved can share and learn from the experiences of the others. The demonstration program will include a balance of institutions based on their size and whether they are public or private.

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

AAU will work with our technical advisory committee to identify the best avenues to pursue to achieve this goal. For example, AAU may wish to form a committee of experts from our institutions and others to recommend best practices for incorporating teaching into university tenure and promotion decisions. AAU may study the role of centers for teaching and learning on campus, or conduct surveys of faculty and students about what does and does not work. AAU also may convene groups of deans, department chairs, and associate provosts for undergraduate education to discuss these issues.

Part of achieving this goal will be to disseminate successful existing efforts to our institutions in ways that are useful and helpful. For example, as CIRTL seeks to expand to additional research universities, AAU may encourage its members to join. AAU can also serve as a broker: for example, working with the Business Higher Education Forum to establish new partnerships between industry and specific institutions or departments.

Goal #4: Work with federal research agencies to develop mechanisms for recognizing, rewarding and promoting efforts to improve undergraduate learning.

As a first step, AAU will examine if there are ways it can aid faculty members applying for National Science Foundation (NSF) grants to adopt undergraduate STEM teaching and learning activities in ways that meet the agency's Broader Impacts criteria. At the University of Wisconsin, the Delta Project (part of CIRTL) has helped principal investigators (PIs) fulfill the Broader Impacts requirement for NSF funding. AAU might help by convening a group of faculty, administrators, and NSF officials to develop ways in which institutions and PIs can fulfill this requirement by engaging in activities that improve undergraduate learning. Other research agencies, such as NIH and the Department of Energy, do not incorporate an equivalent of the Broader Impacts requirements into their merit review process. The engagement of NSF might serve as a model to begin discussions with other research agencies about better aligning federal incentives with faculty engagement in undergraduate STEM education.

Another possibility is to establish named chairs/professorships in STEM discipline-based education research. This could be a cooperative program, funded with federal and state dollars, as well as institutional and corporate funds. The federal government, perhaps through the Department of Education and/or NSF, could provide funding that would be matched by state, corporate, and institutional contributions. The chairs/professorships would be established within schools and/or academic departments to help support researchers working to understand and improve undergraduate STEM teaching and learning within their particular STEM disciplines. Such a program should build on the success of existing privately funded efforts such as the HHMI Professors Program.

The Canadian Research Chairs program might serve as a model. While the Canadian program is aimed at helping Canada attract and retain leading researchers from around the world, the model could be adapted to supporting U.S. faculty who employ research-based methods to improve undergraduate teaching and learning in their respective disciplines. Such a program would help to better integrate research and teaching at the departmental level. Such a new program might also serve as a mechanism to enact recommendations from the National Academies Board on Science Education (BOSE), which is studying discipline-based education research in physics, biological sciences, geosciences, and chemistry.

Goal #5: Determine how best to evaluate and develop effective means for sharing information about promising and effective undergraduate STEM education programs, approaches, methods, and pedagogies.

AAU has surveyed its institutions and compiled examples of different programs to increase STEM retention. We also have conducted a preliminary survey of institutions for activities related to: 1) monitoring the teaching practices used in all of their STEM courses; 2) making teaching practices, independent measures of learning, and student success part of the evaluation and reward system for both individual faculty members and departments; 3) providing training to faculty members on how to implement proven research based practices in their teaching; and 4) raising external funds to implement such training as an institutional priority. A part of the AAU STEM undergraduate education initiative will be fleshing out these examples to produce a best-practices guide for institutions.

Another element of this goal is to determine how best to centralize useful resources for faculty members. The technical advisory committee can provide guidance in how best to accomplish this.

Ultimately, the purpose of the AAU undergraduate STEM education initiative is to provide assistance and encouragement to institutions as they develop and expand their own efforts to improve undergraduate STEM education. Working with our member institutions and other partners, we are eager to assist in effecting change.

Selected Sources—Sources have been cited throughout this document, but this section contains a list of some important general sources and some discipline-specific sources.

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APPENDIX: STRATEGIES FOR CHANGING INSTITUTIONAL AND DISCIPLINARY CULTURES TO ENCOURAGE IMPROVED STEM TEACHING

Following are strategies that have been identified through a review of the literature for changing institutional and disciplinary cultures to assist faculty members in utilizing effective teaching techniques. Examples and resources already exist for most of these ideas.

- Identify and provide professional development opportunities for faculty members to enhance their teaching. Programs such as the National Academies Summer Institute or NSF's Faculty Institutes for Reforming Science Teaching (FIRST) give faculty members the opportunity to learn new techniques to improve their teaching, and then bring what they learn back to colleagues at their institution.

- Teach future faculty members how to teach. The Center for the Integration of Research, Teaching, and Learning (CIRTL) focuses on training graduate students at research universities to teach. The American Physical Society (APS) provides workshops on undergraduate teaching for new physics faculty.

- Recognize and reward good teaching. The HHMI Professors, a group of accomplished research scientists who also are deeply committed to making science more engaging for undergraduates, suggest using awards or named professorships that provide research support for outstanding teachers. Teaching awards can be made at the institutional level, but also at the college or departmental level, which helps send a message about the importance of teaching at those levels.

- Expand the role of teaching in promotion and tenure decisions. This must include rigorous evaluation of teaching beyond student evaluations.

- Develop communities of practice. For example, the HHMI Professors suggest creating teaching discussion groups of junior and senior faculty members. Group members would attend each other's classes and provide critiques highlighting effective or innovative teaching strategies, and identifying ways to increase effectiveness. Group members would also be exposed to a variety of teaching strategies. Other communities of practice could occur across disciplines (facilitated, for example, by centers for teaching and learning on campus) or even across institutions.

- Bring together disparate groups of faculty focused on change. Researchers have identified three groups of scholars who have been working on issues of how to improve undergraduate education and how to successfully disseminate successful techniques: 1) disciplinary researchers, 2) faculty development researchers, and 3) higher education researchers. These groups have similar goals but little interaction. Since they are focused on similar goals, these groups should be brought together (on individual campuses and in the greater scholarly community).

- Recognize and address the factors that influence whether faculty members implement new teaching techniques: Faculty members who attended the National Academies Summer Institute and were later asked about the effects of the experience on their teaching identified the three biggest obstacles to implementing changes in their teaching as: 1) time pressures, 2) balancing responsibilities, and 3) lack of recognition. A survey of physics faculty by Dancy and

Henderson (2010) found the two biggest obstacles to be lack of time and lack of familiarity with these techniques. Henderson et al. (2010) surveyed physics faculty to determine the factors that made them more or less likely to use new techniques. Interestingly, high research productivity and large class sizes were not found to be barriers to use of at least some techniques.

- Provide faculty members with tools that include both curricula and pedagogy, but allow them some flexibility in use. Discussions in the literature indicate that faculty members are unlikely to use prepackaged tools without modifications of their own (i.e. "putting their own spin on it"). On one hand, some modifications may reduce the effectiveness of certain tools. On the other hand, faculty members will, reasonably, want to put their own touch on the techniques they use in the classroom. The Vision & Change guide for teaching undergraduate biology, along with the CourseSource.org set of resources, currently under development, provides ideas about curricula, pedagogy, and assessment. In addition, its modular nature gives faculty members discretion to use it in their own ways without diluting its effectiveness.

- Engage all faculty members, but not necessarily in the same way. Faculty members who teach the disciplines must be an active part of the process, rather than simply consumers of prepackaged tools and "solutions" put together by educational researchers. As Robert Mathieu put it: "It would be a serious error to think that the faculties of research universities are not deeply committed to their roles as teachers, and to the learning of their undergraduate and graduate students. This life purpose is why we are faculty – many of us could pursue research-only positions outside of the university, often with much higher compensation." James Fairweather, in a study of faculty productivity, pointed out that "…policies might reward teaching and research productivity differently at distinct points in the faculty career."

- Link teaching and research in as many ways as possible. For example, applying appropriate research techniques to teaching ("scientific teaching") can help faculty members integrate their teaching and their scholarship. In addition, faculty members can be encouraged to utilize existing mechanisms, such as NSF's Broader Impacts Criteria, to better integrate these activities.