Improving Undergraduate STEM Education at Research Universities: A Collection of Case Studies

Case studies by

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We would also like to thank the authors of the case studies who are leading large-scale efforts to improve undergraduate STEM teaching and learning at research universities.

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Introduction

There is a striking disconnect between the impressive extent of discipline-based research that argues for new approaches to classroom teaching, and the depressingly low rates of adoption of these new ideas. This is despite repeated calls to action from such prominent national players as the President's Council of Advisors on Science and Technology (PCAST), the National Academies' study on Discipline-Based Education Research (DBER), and the Association of American Universities (AAU).

While there is a broad consensus that systemic institutional change is needed within universities to enable continuous improvement of undergraduate STEM teaching and learning, there is little literature or discussion about precisely what those institutional changes should be or how in practice they might be achieved. To help fill this void, the AAU has launched an effort in connection with the AAU Undergraduate STEM Education Initiative to collect case studies that document current and past attempts at large-scale transformations of undergraduate STEM teaching at research universities. These are meant to be a resource for department chairs and deans who are contemplating large-scale efforts of their own.

We welcome additional case studies and invite authors to contact Emily Miller, Director, Association of American Universities Undergraduate STEM Education Initiative at *emily.miller@aau.edu* to discuss submissions.

Sincerely,

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President
Research Corporation for Science Advancement

G. Peter Lepage
Member
Association of American Universities
Undergraduate STEM Education
Initiative Advisory Committee

Case Study 1
The Science Education Initiative:
An Executive Summary of a Large Experiment in Institutional Change in the Teaching of Science

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The Science Education Initiative (SEI) (Wieman et al. 2010) were joint projects carried out at the University of Colorado at Boulder (CU) and the University of British Columbia (UBC). Their stated goal was to achieve widespread improvement of the teaching of science at the respective institutions focusing on use of research-based teaching methods from discipline-based education research. The unstated goal was to answer the questions: is it possible to scale up the use of research-based effective teaching so that it can become the norm within science departments at large public research universities, and what factors inhibit or support such a change?

This effort was unusual in that it targeted the teaching of entire departments, not individual faculty members. A competitive grant program provided relatively large one-time grants (up to $1.85 M) to departments to carry out widespread, and hopefully permanent, changes in the teaching of their undergraduate courses. The changes focused on transforming the instructional methods used by their faculty to incorporate clear learning goals, research-based active-learning instructional methods, and better assessments of learning (CWSEI 2014). This was accomplished via individual course transformations carried out by faculty working with science education specialists. These specialists were usually Ph.D.s in the respective science discipline who were trained in science education research and effective teaching methods as part of the SEI program. Departmental training programs for teaching assistants (TAs) were also established.

While there have been several preliminary reports published on these efforts, a long paper is being written that provides the first detailed discussion of the design and findings of these initiatives. This paper is too large for this volume, and so here we provide a preliminary summary of some of the main findings of that longer work. There is also a large amount of material on the SEI, as well as extensive resources on science teaching, examples of transformed courses, and videos of exemplary courses available on the website *www.cwsei.ubc.ca.*

Table 1: Key Aspects of the SEI Programs as of Summer 2015

	CU	UBC
Total funding amount	$5.3 M (USD)	$11.3 M (CAD)
Funding per department	$150-$860 K (ave $650 K[1])	$300 K-$1.85 M (ave 1.4 M[1])
Number of departments	6 CHEM, GEOL, PHYS, 3 BIO Department + small pilot in ASTROPHYS	6 BIO, COMPSCI, EARTHSCI, MATH, PHYS-ASTRO, STATS + pilot in CHEM
Total number of full- and part-time science education specialists	24	50
Courses/credit hours transformed	71/53,000/yr	164/139,000/yr
Number of faculty that changed teaching methods	102	180

The most important results of this work are:

1: It is possible to achieve widespread change within departments. The most meaningful data are the number of faculty that have substantially changed their teaching to incorporate more effective research-based methods, the number of courses taught with such methods, and the number of students and credit hours per year impacted by these changes. At UBC some 139,000 student credit hours in math and science, across 164 courses, are being taught in a substantially better way, involving about 180 faculty. This represents well over half the total credit hours provided by the participating departments and about half the credit hours provided by the entire college. In the most successful departments, nearly 90% of the faculty adopted new teaching methods and nearly all of the undergraduate credit hours have been impacted. There is good evidence of sustainability of these changes over a time scale of a few years (Wieman et al. 2013), and indications that such teaching methods are now seen as the norm by both students and faculty in those departments. The level of success however varied dramatically by department, with the organizational structure and management of the department, and the culture of the discipline, playing major roles.

2: Nearly all faculty can learn to use new teaching methods effectively, but there is a significant initial learning curve. This is when faculty are learning what this form of teaching looks like and feels like in their own class and understanding the theory of learning on which it is based. Assistance getting

[1] Averaged among 6 fully-funded departments at CU and 6 fully-funded departments at UBC.

up that initial learning curve is important, but once that is accomplished, faculty can function well and continue to improve on their own. They then readily adopt these new teaching methods in other courses without any support.

3: Over 120 research papers based on SEI activities have been published as of this writing, with a number of others in preparation or review (CWSEI n.d.).

4: While many initial aspects of the program did not work as intended, there are three elements of the program that did turn out to be clearly effective and would be applicable in many contexts where there is a desire to improve undergraduate STEM teaching.

a. A competitive grant program for departments with substantial funds at stake. This produced widespread attention and discussion of undergraduate education and how it might be improved, discussion that had not happened previously. In many cases, it also produced the effort necessary to prevent a small opposition from stopping an effort with broad departmental support.

b. Science Education Specialists — experts in the discipline (usually new Ph.D.s) with training in scientific teaching methods and research ("Science Teaching and Learning Fellows (STLFs)", also known as STFs at CU) that worked with faculty to change specific courses were a highly effective way to provide necessary knowledge, expertise and time-saving assistance. The salaries for the STLFs were the primary program expense. These STLFs are hired by the departments and undergo a semester long on-the-job training program in science education research, discipline specific education research, effective teaching methods, and working effectively with faculty. A detailed discussion of what the STLFs do and the training program for them is available at the CWSEI website. *http://www.cwsei.ubc.ca/resources/STLF-develop.htm* . Initial concern as to their long-term career paths has disappeared, as they have found it easy to find good jobs. The majority of them have chosen to take tenure-track teaching positions, for which there is a growing demand and STLFs are uniquely well qualified. Most of the others have taken tenure-track faculty positions focusing on discipline-based science education research or positions in offices of faculty development.

c. Establish a few good examples that others in department can see and discuss. This reduces fear and encourages adoption among the broader population of faculty.

d. We initially put nearly all of the funding into supporting STLFs, with very little funding for the SEI central or explicit incentives for faculty. This was a mistake. More progress was made when faculty had explicit benefits for participating and when there was enough SEI central oversight of department programs to intervene when progress was lagging.

5: The institutional incentive system is the dominant barrier to adoption of both better teaching methods and collective departmental practices that would make education more effective for the students and teaching more efficient for the faculty. Faculty and departments align their priorities and efforts with the institutional incentive system, which means a low priority for undergraduate education. The primary exception to this is when faculty see that teaching can become a personally more rewarding activity if they use different methods. Those personal incentives can then shift their priorities. Without a change in the formal incentive system, additional funds, as used in the SEIs, will be needed to provide incentives to the faculty to expend time on learning how to improve their teaching, implementing changes, and iteratively improving.

6: It would be possible to carry out similar changes as in the SEIs with considerably less money than we used, if the incentive system supported the change. To the best of our knowledge, all faculty who changed their teaching in the SEI program saw it as a voluntary activity which they were free to pursue or abandon at any time without consequences, because of the lack of formal incentives. This resulted in considerable inefficiency in the process. There were many cases where an STLF was paid to work with a faculty member to change how a course was taught, but when it came time to actually make changes, or put in the necessary time, the faculty member was unwilling. There were also a few faculty who were assigned to teach a course which had been extensively transformed to use improved teaching methods who then rejected all the changes and the learning objectives for the course and the assistance of the STLFs, and taught the material they chose using hastily constructed lectures.

If the faculty members would see the adoption of high quality teaching methods as a necessary part of their job, change could be accomplished with little or no support. However, we believe that to make the change smooth and effective, while avoiding disruption in research productivity, it would require having 1 or 2 STLF-type people in a department for several years to support the effort. These STLF-like people would provide the faculty with appropriate references, guidance on the preparation and use of instructional materials, and discipline-centric teaching expertise, and guidance. After that transition period, the change could likely be self-sustaining as materials and expertise are shared and passed along to new faculty. These better teaching methods are not inherently more expensive. However, to accomplish such an improvement in teaching methods without a change in the formal incentive system will require additional funds, as used in the SEI, to provide incentives to the faculty to expend time on learning how to improve their teaching and redesigning courses.

7: The original hypotheses that science faculty would be convinced to teach differently primarily through seeing research data on the effectiveness of different methods was largely incorrect. If the data contradicted their beliefs and self-image as a good teacher, faculty would find reasons not to believe it. Seeing these interactive teaching methods in contexts similar to their own classrooms did help convince faculty to change, primarily due to the fact that the students are much more engaged in learning and show interest in the topic.

8: There was very limited progress at achieving departmental ownership and oversight of the content of courses and how they were taught. There were also few departmental efforts to improve the efficiency of teaching by making the handoff of courses more efficient and ensuring transitions between courses in a sequence were well coordinated. Apparently, these were too large a change in departmental cultures and modes of operation.

9: It required persistence and flexibility to achieve good results. In the initial years at both institutions there were major problems in many areas, particularly in figuring how to establish and maintain good STLF-faculty working relationships in departments. Over time, numerous changes were made and solutions emerged that dealt with these problems. As a result of these changes the program was working much more smoothly and effectively in later years.

a. Substantially increased oversight and specificity as to deliverables was necessary to ensure progress and follow through by departments and individual faculty to meet their commitments. This included specifying timelines for what courses were to be transformed, what faculty involved in transforming those courses would do, and what the teaching assignments would be for multiple years for any course being transformed.

b. Having funding contingent on progress, rather than being fully committed up front. In one department funding was terminated early after a new Chair was appointed who declared he had no intention of living up to the commitments made in the department's proposal. In another, funding was suspended due to poor performance caused or exacerbated by organizational problems, but then reinstated after major changes in departmental leadership and organization around undergraduate education. It is now working well.

c. The departmental leadership is critically important. A supportive Chair is necessary, although not sufficient. The influence of the Dean was most clearly evident through their selection (or not) of a Chair who was supportive of the SEI.

d. The concept of beginning with transforming the large introductory courses and then systematically working upward through the curriculum did not work. It turned out that large multi-section, multi-instructor courses were the most difficult to transform, and it was more effective to find receptive faculty, and then support them to transform whatever course they were working on.

10: Virtually all faculty want to teach well. The fact that faculty may use methods that are not optimum is not the result of not caring, rather it is the result of being unconvinced of the value of changing, or the relative benefits compared to the time it would require. When they pursued actions counter to what we desired, there was no maliciousness in their actions, rather it was the result of having different values and priorities, largely as a result of the incentive system and the culture in which they were working.

11: Ultimately, the primary determinant of success was the overall quality of the organization and management of the department. The sole exception to this was in mathematics, where some combination of the culture of the discipline, the culture of the department, and the funding model for the research program led to the faculty being uniquely resistant to changing the teaching methods used.

12: We developed several instruments to better measure the teaching and track changes that were made over the years. The Teaching Practices Inventory provides a quick and easy way to characterize all aspects of the teaching of a course, and to determine the extent of use of practices that research shows lead to better learning (Wieman and Gilbert 2014). This was used to show substantial changes in the practices used by a department (Wieman and Gilbert 2014). The Classroom Observation Protocol for Undergraduate STEM (COPUS) allows people with relatively little (1.5 hours) training to reliably characterize how instructors and students are spending their time in class (Smith et al. 2013). Finally, a protocol was developed that allows observers to characterize the degree of engagement of students in a class in order to determine how that varies with different teaching activities (Lane and Harris 2015). The last is intended to be more of a limited-use research instrument, while the first two are intended to be used (and are being used) on a more routine widespread basis.

13: Several other barriers to improving teaching were frequently encountered. First was the "tyranny of content". It was common to have instructors agree that these new teaching methods were better, but felt they had to stick with standard lecturing in order to cover all the material listed in the course description. There was a general consensus that too much material was being covered for students to absorb in cases where the instructor felt much greater pressure to cover material rapidly; but the instructors nevertheless felt compelled to rush through it all, apparently motivated largely by historical precedent.We have found that for reasonably well polished and paced courses, 90% or more of the material could be covered with an effective active learning course, while achieving substantially greater learning (e.g. Jones et al. 2015).

Less common but not unusual were concerns that these methods were only suitable for the weaker students, they were babying students, and they would harm the top students. As more students became familiar with these teaching methods, the students themselves, particularly many of the strongest students, provided the most powerful and articulate arguments against these ideas. Data on learning from students at the institution contradicting these fears also likely helped.

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Case Study 2

The Carl Wieman Science Education Initiative at the University of British Columbia:

A Dean's Perspective

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Introduction

In 2007, the University of British Columbia launched a major science education initiative led by Prof. Carl Wieman with the goal of transforming undergraduate science and mathematics. Distinctive features of this initiative include the large scale ($11M over 8 years), systemic approach, the focus on department-centred proposals, and the critical role played by science teaching and learning fellows (see Wieman, this volume). Eight years later, 167 courses have been transformed resulting in improved learning for more than 15,000 individual students/year enrolled in Science, Applied Science, Arts, Commerce, and other programs. Key challenges that emerged include learning what compels individual instructors to embrace research-based teaching practices, determining who controls what students should learn in a course, and sustaining the transformations after the initiative finishes.

Over the past two decades, brain research, cognitive psychology, and university science classroom studies have advanced our understanding of how humans learn and how best to enable student learning. (e.g., Ambrose et al., 2010). For STEM disciplines, an important review by Hake (1998) involving 62 introductory physics courses demonstrated that students taught using active learning techniques exhibited more than twice the gains in conceptual learning compared to students taught using traditional methods. The recent U.S. National Academy of Sciences (Singer et al., 2012) review of ~1,000 STEM research studies clearly demonstrates "research-based instructional strategies are more effective than traditional lecture in improving conceptual knowledge and attitudes toward learning ... Effective instruction involves a range of approaches, including making lectures more interactive, having students work in groups and incorporating authentic problems and activities." Many individual university faculty members across North America are adopting these methods, but few universities are attempting to do so on an institutional scale. We know how to dramatically improve student learning, but how do we individually and collectively change the way we teach? This is as much a question of institutional culture change as it is a question of how best to deploy limited financial and time resources. In this paper I briefly describe how a large-scale science education initiative at UBC has succeeded at improving student learning across all science departments, and my perspective as Dean on important keys to success and lessons learned.

The Carl Wieman Science Education Initiative at UBC

UBC's Carl Wieman Science Education Initiative (*http://www.cwsei.ubc.ca/*) is a research-based approach to improving undergraduate science education that has involved more than 100 instructors across the Faculty of Science. [Note, a Faculty in a Canadian university is equivalent to a College in the United States.] Launched in 2007, UBC and donors have invested approximately $11M to transform undergraduate science teaching at UBC. The UBC investment was made by the Provost and at $1.5M/yr is equivalent to roughly 1.5% of the Faculty of Science's annual operating budget. A key initial assumption was that one-time resources were needed to transform courses, but once transformed the courses would not require additional resources. We plan to continue to invest resources (at 25-50% of the CWSEI funding rate) to support transformation of additional courses, ongoing measurement and scholarship efforts, evidence-based refinement of our approach, and the training of new faculty.

The overall CWSEI approach involves three steps (Wieman et al., 2012):

1. Establish what students should learn. These learning outcomes or learning goals need to be explicitly stated and ideally most can be measured.

2. Scientifically measure what students are actually learning. Several scientific disciplines have developed measures of conceptual learning for specific topics, with the best example being the Force Concept Inventory developed to assess student learning in introductory physics (Hestenes et al., 1992).

3. Implement teaching methods aimed at maximizing learning. Such methods include effective use of personal response systems (clickers) into lectures, peer instruction, group work, interactive lectures, and computer simulations. This is an iterative process with teaching methods revised based on measuring the effect on student learning. These techniques increase feedback to students and instructors about student learning that is largely lacking in traditional large lectures.

The CSWEI focuses on the academic department as the cultural unit for teaching, with faculty experts and the department determining what students should learn in each course and program. Funding was based on department proposals that needed to demonstrate department-wide commitment and readiness to undertake sustained effort to improve science education, with a clear plan and timeline for transforming courses. Transforming a course is typically a multi-year project and requires three iterations—a planning term, an implementation term, and a revising and refining term. All proposals made extensive use of limited-term science teaching and learning fellows (STLFs). These science education specialists, commonly post-doctoral scholars, have disciplinary content expertise, and developed pedagogical expertise through central training and mentoring by the CWSEI team. STLFs work closely with faculty members to develop course learning goals, design learning approaches that promote learning, construct appropriate measurements of student conceptual thinking and learning, and publish results of implementation and measurement design.

UBC's Faculty of Science consists of nine departments spanning the life sciences, physical sciences, and the mathematical and computational sciences. The Departments of Botany and Zoology, with contributions from Microbiology and Immunology, deliver a single undergraduate Biology program. The creation of an Associate Head, Biology, reporting to the Heads of Botany and Zoology, proved to be an important organizational change that enhanced success in this large undergraduate program delivered by multiple departments. The Department of Earth, Ocean and Atmospheric Sciences and the Department of Physics and Astronomy successfully undertook large transformation projects and their efforts are mature and largely complete. The Biology program and the Departments of Computer Science and Mathematics were funded for large projects; these efforts are maturing, but are not yet complete. The Departments of Chemistry and Statistics were funded for more limited transformation efforts.

As of Fall 2014, 167 undergraduate science and math courses, involving 150,000 student credit hours, have been fully or partially transformed by the CSWEI, resulting in improved student learning in 67% of the student credit hours delivered by the Faculty of Science. Most of these courses were large first- and second-year lecture courses, with 100 to 450 students per lecture section. In science departments, most of these transformations are "flipped" courses with information transfer moved outside the lecture and research-based active teaching and learning practices incorporated into the lecture. In mathematics, most of the CWSEI efforts involved incorporating online homework tools and tutorials into first and second-year classes with relatively few changes made to the lectures. Faculty surveys conducted in 2007 and 2012, validated by classroom observations, document that the CWSEI is successfully increasing the adoption of research-based teaching practices across the Faculty of Science

(Wieman, 2015). Our data suggest that the changes made to improve student learning are being sustained. Based on the 2012 survey, only one out of 70 UBC faculty members who tried research-based teaching methods with CWSEI support had stopped using such methods more than one year after that support had ended. Even more encouraging, most of those instructors are transforming additional courses with little or no help from the CWSEI.

A Dean's Perspective

In a separate paper in this volume, Prof. Carl Wieman describes the important results and lessons learned based his extensive experience leading major science education initiatives at the University of Colorado and the University of British Columbia. Here, I add my perspective as Dean of the Faculty of Science at UBC from 2006 to the present.

1: Success is more likely to be obtained (and sustained) when there is critical mass of educational leaders within a department who have the strong support of their department head. Critical mass may already exist in some departments, but will need to be built in others. Departments as a whole must own the challenge of improving student learning and rewarding educational transformation efforts. Departments have limited bandwidth for major initiatives. If a department is already undertaking a major project, such as major curriculum reform or strategic planning, attempting also to transform the way they teach can prove overwhelming. I believe the overall leader of the initiative is also critical, and at UBC we have benefitted greatly from the leadership of Carl Wieman, winner of the Nobel Prize in Physics and numerous science education awards.

2: Success requires close collaboration between the science education transformation team and the Dean's office. Faculty need to hear a consistent message regarding the importance of improving student learning. At UBC, Carl Wieman, as Director of the CWSEI, reported directly to the Provost. CWSEI was focused exclusively on improving teaching practices within the Faculty of Science, so having this initiative reporting to the Provost rather than to the Dean created both opportunities and challenges. Department heads (and faculty members) report to the Dean, not the CWSEI Director, so departments and faculty could choose not to listen to CWSEI directives and advice (of course, the same could be said about the Dean's directives and advice). The substantial financial resources provided a major incentive for most, but not all, departments to engage fully with the CWSEI.

3: Organization change is hard, particularly in the absence of a crisis. Universities have been around for centuries and academic traditions are deeply ingrained. Groups, individuals, and the press have argued that STEM education is in "crisis", but it lacks the emergency and visibility of other crises faced by universities, like steep reductions in government funding.

Changing the collective teaching culture of a university requires a sustained commitment from individual faculty members, department leaders, and administrators over a period of 5-10 years.

4: Each faculty member has a different view of what constitutes compelling "evidence" that would lead them to change the way they teach. Many faculty are not aware of research in science education and cognitive psychology, and can be quick to dismiss research studies from these disciplines as not relevant to their field or as being soft science. In some cases, discipline-specific education research data from their institution can prove more compelling. At UBC, Delauriers et al. (2011) showed that active engagement techniques increased student learning by a factor of two in a large, multi-section introductory physics course for engineers. This study helped convince a number of faculty that these techniques will work for UBC science students. In other cases, respected peers successfully transforming their courses and conveying their enthusiasm proved to be a compelling factor. Most faculty members would like their students to perform better on exams and when faculty see improved results on exams, this can lead to the adoption of research-based teaching practises. Citing high failure rates in specific courses as evidence of the need to change teaching practices was generally not effective, because faculty were quick to blame students for not working hard enough, to blame the Dean for trying to lower academic standards, and to blame admissions for not recruiting better students.

5: University policies and procedures may pose challenges to success, but these are very difficult to change and should not be viewed as absolute barriers to success. Wieman (this volume) asserts that formal institutional incentive systems are the dominant barrier to adoption of better teaching methods. Promotion and tenure criteria for professors at research universities emphasize the importance of both teaching and research, but research excellence tends to be easier to assess (or at least quantify) than teaching excellence. Student's evaluations of teaching play a significant role in assessing teaching excellence, but such evaluations can be influenced by many factors and do not measure student learning. Peer evaluations of teaching, which are required at UBC, can help, but the peer review team needs to include faculty who support the adoption of research-based teaching methods. Increasingly I see evidence of faculty members adopting scientific teaching methods in promotion and tenure files. At UBC, we benefit greatly from having a tenure track for teaching faculty, whose promotion and tenure depends on excellence in teaching and educational leadership. A number of our teaching faculty have become educational leaders in their respective departments, demonstrating and supporting adoption of new teaching methods, collecting data on the resulting outcomes, and publishing the results. Looking ahead, we have the opportunity to quantify the extent to which modern teaching practices are used through classroom observation protocols like COPUS (Smith et al., 2013). Other policies that need to be examined, and modified where possible, include measures of teaching effectiveness used for evaluating faculty for salary increases, promotion and tenure; collective agreements for faculty and teaching assistants; and behavioural research ethics approval processes when collecting data for evaluating teaching effectiveness.

6: From my perspective the biggest ongoing challenge is *Who determines what students should learn?* The instructor? A faculty committee? The department? The government? The students? The Dean? OK, probably not. Does one's answer to this question change if the course is a pre-requisite for another course, or if the course is a required course as opposed to an elective, or if the course is a multi-section course, or if the course fulfills a general university requirement? Different departments have different teaching cultures. In some departments, the tradition is the individual faculty member has full control over the course, including learning outcomes, and suggestions to change are met by (false) assertions that one is infringing on their academic freedom. In other departments, the culture is for greater department involvement in determining learning outcomes in individual courses. Many faculty members are passionate about the courses they teach, which is a wonderful asset, but learning goals cannot be left solely in the hands of individual faculty members. Early on in the CWSEI we required all first year courses to develop explicit learning goals, which appears to have helped our efforts.

7: The biggest concern I hear expressed by faculty is the need for time to change their courses and, to a lesser extent, sustain these changes. Faculty members have many competing demands on their time and increasing the time they devote to teaching must come at the expense of research or personal time. Most of the CWSEI funding is directed toward reducing the amount of time required to transform one's teaching. Most departments make use of science teaching and learning fellows who work closely with faculty members who are transforming their courses. In some departments, instructors are provided with course buyouts (reduced teaching) during the planning or implementation term. In other departments, increased TA support for lectures was important. Completely transforming a course can be a daunting task. In many cases it may be better to start with a more modest set of changes focused, for example, on 2-3 topics that the instructor has struggled to teach well in the past.

8: Reward and celebrate your best teachers, in ways big and small. Nominate your best teachers for department, university, and national teaching awards. Take the time to thank individual faculty members for teaching well and incorporating the latest scientific teaching techniques. Recognize that you have excellent instructors already using research-based teaching practices.

Talk early and often about the importance of teaching and teaching well, and back up your talk when conducting faculty merit evaluations. Let faculty know that a dip in one's student evaluations may occur during the initial implementation of new teaching practices, and that they will not be punished for such a dip.

9: Sustaining science education initiatives through changes in personnel requires constant attention. Carl Wieman led our efforts at UBC until 2010 when he moved to the U.S. Office of Science and Technology Policy. At that time, Sarah Gilbert took over the leadership of CWSEI. Wieman and Gilbert have now moved to Stanford University and the CWSEI has been integrated into the Faculty of Science's Centre for Learning and Teaching. Since the CWSEI began in 2007, every department head has changed and I consider support for the CWSEI to be an essential quality when assessing head candidates (Wieman, this volume). STLFs typically serve 2-3 years before obtaining faculty positions in higher education, so there is a need to continually recruit and train new STLFs.

10: Systemic institutional change is about individual people. Individual faculty members need to recognize that changing one's teaching practises is good for their students and, done well, can be very rewarding. Young STLFs trained in the latest pedagogical techniques need to learn to work closely with experienced instructor, and vise versa. Students need to take responsibility for their own learning and learn how to learn in new ways.

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Case Study 3

Establishing an Institute to Integrate the Research and Teaching Missions of a Research University

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Introduction

A national movement is afoot to align how we teach with current research on how people learn. Because of widespread availability of technology, students have immediate access to all sorts of information. Professors are no longer the primary source of facts—the need to "profess" is historical rather than necessary. These changes are driving exciting conversations about how best to leverage the value the research university in service of undergraduate learning. The College of Natural Sciences at The University of Texas at Austin has capitalized on this unique moment in time by finding innovative ways to integrate the two missions of the research university: research and teaching.

The Freshman Research Initiative is an exemplar of how we have accomplished this. FRI's radically different approach involves large numbers of freshmen and sophomores in conducting scientific research in through series of courses called "streams." Each stream follows the same three-course sequence: a research methods course followed by two semesters of research in one of 25+ unique areas, from computer science to astronomy to biochemistry. Each stream of ~40 students is led by a postdoctoral-level Research Educator (RE) and a tenure-track/tenured faculty Principal Investigator (PI). The RE's role is essential to FRI because each RE mentors all of the students in the stream, which would not be practicable in a typical research lab. Through FRI, ~800 students (>40% of our incoming college class, 50% women, 40% students from backgrounds underrepresented in STEM) earn introductory lab course credit while they conduct research. Both students and faculty appreciate the authenticity of research as a learning environment. FRI makes access to research experiences more equitable, since students are able to do research while they make progress in completing their majors instead as an additional time commitment outside of class.

The program has fundamentally changed the undergraduate experience in our college to one that accomplishes research and teaching simultaneously. Longitudinal tracking data indicate that this has multiple important effects on students. Thirty-five percent more FRI students graduate than a matched sample of their peers. For Latino/a students, this effect is even more pronounced as their graduation rates double relative to their matched peers who do not participate in FRI. FRI students also have higher upper-division GPAs in their science courses and more go on to graduate and professional schools: 32% of FRI students versus 9% of non-FRI students in the College. More than 130 FRI students are co-authors on published or in-press research articles.

The college's 2013 strategic plan called for the establishment of a new center that builds beyond FRI by finding new, creative ways to integrate research and teaching. Here we tell the story of the conception and design of this center, *Texas Institute for Discovery Education in Science*, or TIDES, and describe the variety of ways TIDES is catalyzing the integration of research and teaching. These principles are guiding our work:

- **Design based on empirical evidence.** We examine current research on teaching and learning and use this knowledge to inform what we do.
- **Capitalize on local resources and interests.** We continuously assess local needs, capacities, and interests, and use assessment results to design strategies.
- **Maintain flexibility.** In a system as complex as a research university, one-size-fits-all is not an option. We use multiple strategies to encourage and support faculty in being innovative in their teaching.
- **Develop an ethos of evaluation.** We make education research and evaluation an integral element of all initiatives. We use the resulting data to inform decisions about improvements, determine efficacy, demonstrate impact, and attract investment.

Background

We started by establishing an advisory board of faculty who are forward thinking about education. These faculty are known for both their research and teaching accomplishments, and represent diverse disciplines in the college. We seek their feedback on ideas and strategies during periodic meetings and via email. In consultation with these advisors and other stakeholders, we articulated the mission of TIDES: **to catalyze, support, and showcase innovative and evidence-based undergraduate science education.** This mission reflects our interests in collaborating with faculty to create new ways of integrating research experiences into the undergraduate science curriculum, and to expand faculty use of research on learning to improve their teaching.

We then set about assessing the landscape of undergraduate education in the college. We asked what faculty needed to innovate in their teaching and what strengths we could leverage to more fully engage undergraduates in the science research endeavor. The loudest and clearest message we heard is that faculty members were not trained as teachers and wanted guidance on how to teach well. They didn't know where to find resources that had been shown to be effective for improving student learning, or how to make use of them. Existing resources for improving teaching were not being tapped because they were perceived as disconnected from the challenges of teaching science courses. Faculty who were already changing their teaching emphasized the importance of communicating that teaching well does not have to be more difficult, and it can be more effective and more fun.

We also saw that the timing was right for the launch of TIDES based on institutional support for innovative and evidence-based teaching. For example, the university is engaged in an ongoing Campus Conversation, with leadership from the president and provost, to encourage innovation at the intersection of research and teaching. FRI has been held up multiple times during the Campus Conversation as a model. The Provost also launched a Teaching Fellows program, which identifies and supports faculty to lead projects aimed at improving teaching and learning. Several of the Provost's Teaching Fellows are faculty in the College of Natural Sciences, and are already serving as another source of advice for TIDES activities and pool of potential mentors for faculty making improvements to their teaching.

Finally, we extensively reviewed research on individual and organizational change, especially related to teaching and learning. We learned that faculty try out new strategies when they are dissatisfied with their own teaching, such as when they are tired of teaching the same concepts in the same way or when they feel like students aren't engaged in class. We also learned that faculty become interested in changing how they teach when they collect data in their own classrooms that indicate their students are misunderstanding key ideas. We found studies that indicated that faculty will consider teaching differently when a colleague they respect encourages them to do so, or when they collaborate with an education specialist (e.g., a biology education researcher in a biology department). We came to recognize that colleagues could function as social persuaders ("try it!") and normalize the difficulty of trying new ways of teaching ("I had trouble with this too, and this is how I handled it"). We were compelled by the unique role that education specialists could serve by advising faculty on how to go about using particular teaching strategies effectively. For example, a faculty member could learn about asking clicker questions by attending a workshop or reading an education paper, and an education specialist could help them write useful clicker questions and manage class discussion about the question based on students' responses.

Strategies

With all of this in mind, we opted to take a multi-pronged approach that fits our guiding principles (i.e., *design based on empirical evidence, capitalize on local resources and interests, maintain flexibility, develop an ethos of evaluation*). Specifically, we are:

- Inviting and supporting **faculty-driven innovations** that integrate research experiences into classroom teaching,
- Building faculty awareness and effective use of **research-based teaching methods**, and
- Collecting the **assessment** data we need to inform the development of new programs as well as determine efficacy and demonstrate impact of educational innovations.

We are pleased and proud of FRI as an innovative and effective model for integrating research and teaching in lab courses. We are working with faculty to innovate within the FRI model. As faculty develop collaborations that take their research in new directions, we are creating new, interdisciplinary streams that engage students from diverse STEM majors (maintain flexibility, capitalize on local resources and interests). We are studying FRI to identify causal mechanisms that underlie its efficacy *(develop an ethos of evaluation).* We want to identify which features of the program are necessary and sufficient to achieve the student outcomes we are observing.

The next, natural opportunity is to create and test new models for integrating research into "lecture" courses. We are working with faculty to carry out their visions for novel ways to accomplish this. For example, two of our faculty are partnering to guide students in conducting a research project as part of the developmental biology lab and lecture courses they teach *(capitalize on local resources and interests).* Students in the lab course conceived of and conducted a study of environmental factors influencing sea urchin development. Then they reported their findings to students in the lecture course, who worked within the constraints of the lecture course time and space to collect a much larger dataset than could have been collected by the small number of students in the lab course. The lecture-course students wrote up the results of their analyses, which will be shared for the next cohort of lab-course students to build on through new investigations. TIDES staff are advising on the project design and implementation based on current research related to course-based undergraduate research experiences *(design based on empirical evidence).* TIDES staff are also conducting the formative and summative evaluation *(develop an ethos of evaluation),* thus helping the faculty learn from and improve their work.

We have launched an array of options for faculty to engage at different levels in thinking about how to apply research on learning in their teaching *(design based on empirical evidence, maintain flexibility).* We have established a monthly, lunchtime Scientific Teaching workshop series. During these sessions, faculty learn about effective teaching strategies or tackle issues they are facing in their teaching. We have selected workshop topics based on faculty interests *(capitalize on local resources and interests),* including active learning in large courses, assessment, differentiated instruction, and collaborative learning. In response to requests from faculty, postdoctoral associates, and graduate students, we have launched professional development workshops on mentoring undergraduate researchers using an evidence-based mentoring curriculum *(design based on empirical evidence, capitalize on local resources and interests).* We are tracking participation in these sessions and collecting feedback to make improvements and inform future offerings *(develop an ethos of evaluation).*

Starting next year, we will offer more intensive professional development on teaching and learning. These sessions will be scheduled in the summer for current faculty and during orientation for new faculty. In the meantime, we have selected a group of faculty to participate in week-long professional development offered at the national level. We anticipate that these individuals will be able to apply what they learn to their own teaching, and will be important for expanding our capacity to support teaching excellence across the college. For example, these faculty can collaborate in facilitating teaching professional development and serve as mentors for other faculty who are innovating their teaching *(capitalize on local resources and interests).* We are building a web-accessible teaching resources portal to complement these professional development offerings. The portal will feature effective teaching strategies accompanied how-to advice and video examples *(design based on empirical evidence).*

We recognize that workshops are useful for raising awareness and prompting faculty to try new strategies. More personalized and sustained approaches are necessary for faculty to get feedback on their teaching and support when teaching innovations don't go as planned *(design based on empirical evidence).* Thus, we are developing plans for mentoring and coaching programs. At the request of faculty *(capitalize on local resources and interests)*, we have conducted a handful of teaching observations and one-on-one consultations. We are exploring options for peer observations of teaching that are primarily low-stakes and formative in nature. We are also exploring methods for soliciting constructive feedback from students at the mid-term, when faculty still have time to make improvements. We will make decisions about how to formalize these efforts based on results from pilot testing *(develop an ethos of evaluation)* and our review of relevant research *(design based on empirical evidence).*

To accomplish this work, we have staffed TIDES with individuals who have knowledge of undergraduate science teaching and learning, and skills in professional development and education research and evaluation. We have also hired a research analyst who is spearheading several studies related to undergraduate education programming across the college *(develop ethos of evaluation).* These studies will examine college-level student data to identify areas of need and opportunities for action, and will document the teaching landscape across the college to serve as a baseline for documenting how teaching changes. These studies will also aid in identifying departmental, college, and institutional factors that afford or constrain instructional change.

Conclusion

Even though we are just beginning TIDES, we believe that others can adapt or adopt our strategies to promote change on their campuses. By designing our programs based on empirical evidence, we are increasing the likelihood that they will be effective. By capitalizing on local resources and interests, we are leveraging the assets of a research university—of The University of Texas at Austin College of Natural Sciences in particular—to offer a unique and impactful educational experience to undergraduates. By maintaining flexibility, we are enabling a level of autonomy in teaching change that aligns with the culture of academic research and can catalyze teaching innovations. By making education research or evaluation a part of all of our efforts, we will have data useful for improving undergraduate learning and informing reform efforts. We will also be positioned to test models of learning and instructional change in higher education. We look forward to sharing our lessons learned and to learning from others who are attempting reform in undergraduate STEM education.

Case Study 4

Launching a Large-Scale Transformation of STEM Teaching at a Research University

G. Peter Lepage
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Introduction

The Association of American Universities (AAU) has launched an effort to collect case studies from deans and department chairs documenting large-scale efforts to improve STEM pedagogy at their institutions. This document is one such case study, documenting my attempt, as (then) Dean of Arts and Sciences at Cornell University, to launch an overhaul of introductory science teaching at Cornell. This project started in September 2012, and much of the early effort focused on institutional changes needed to support long-term improvements in pedagogy. The Cornell project grew out of several high-level considerations:

- **Incentives:** Discussions of institutional change to support teaching tend to focus rather quickly on faculty incentives, and, particularly, on the criteria for tenure and promotion. There is no question that these incentives affect how faculty members prioritize their time, but such incentives are deeply ingrained and hard to change quickly (though we should try). Despite these formal incentives, a large majority of the faculty takes teaching quite seriously and devotes considerable time and effort to it. They are motivated partly by a general commitment to high standards, but more importantly by a genuine concern for the well-being of their students. This strong commitment to students acts as an informal incentive that can be leveraged to improve STEM pedagogy, even as institutions continue to struggle with their formal incentive structures.
- **Resources:** One can debate the extent to which the lack of formal incentives is insurmountable, but there is no question that lack of resources is a

challenge, and especially lack of time. Professors need large amounts of time to update their teaching approaches from what they learned when they were students to what is recommended today. Today's faculty member has no free time at all, particularly as funding agencies and universities make ever increasing bureaucratic demands on individuals. A faculty member who wants to change how they teach needs time and/or help to: research the considerable teaching literature about general approaches and about teaching specific topics; create completely new kinds of pedagogical material for every single lecture; poll students to evaluate changes as they are introduced throughout the semester; poll colleagues ahead of time to see what is really needed and expected from the course, so learning goals can be identified for every single lecture; etc, etc, etc.

- **Role of Departments:** Even with time and help, teaching innovation is daunting for just a single professor in a single department, particularly if the professor is not yet tenured. Where teaching innovation has worked well, it has almost always involved a team of professors working with the active support of their department chair and the blessing of their colleagues—that is, it has been a departmental project. Not every colleague has to believe in the project, but there need to be enough people who take it seriously that the effort can't be ignored. A major teaching innovation is much more likely to survive into the future, as teaching teams change, when it is a team project sanctioned by the department and promoted or led by the chair. It is much more likely to survive if the courses affected are seen to be owned by the department collectively, as opposed to the individuals teaching them.

  A team effort also makes it possible and safer for young faculty to participate, which has important long-term implications for teaching changes in a department. If their chair is driving the project, all faculty members will feel less vulnerable to student criticism (an issue sometimes in the early stages) when their performance is evaluated at the end of the year (by their chair).

- **Key Institutional Players:** The department chair is a key institutional player in any attempt to change a department's teaching culture, and propagate those changes into the future. The chair controls departmental resources, and especially teaching assignments, which can make or break a teaching innovation. The other key institutional player is the dean, because the dean sets support levels for departments, and has access to resources on a scale that can make a difference (one-time costs of $1M to $2M per department spread over 5 or 6 years). Given the structure of most universities, the dean is likely more important to such an effort than anyone else in the senior administration, including the provost and the president.

Ideally the dean also works to motivate departments and faculty to participate in such efforts. This could be through legislation or mandates, but it is faster and probably more effective to reward interested departments and individuals with sustained attention (lots of meetings) and adequate resources. The dean's investment in the project should be unambiguous, enthusiastic and public.

The dean's direct involvement shifts the incentives, compensating to some extent for the lack of formal incentives: obviously chairs are highly motivated to maintain good relations with their dean. Similarly the chair's interest and enthusiasm in the project creates incentives for individual faculty members: for example, those heavily involved in the project might expect some credit from the chair when their salaries are set at the end of the year.

This document focuses on the launching of the Cornell project. What follows is a short history of the project to date, a discussion of likely pitfalls, and some conclusions. The college's Request for Proposals, which describes the project in some detail, is included in the Appendix.

Project History

The Cornell project focused on new pedagogical approaches that have been shown to be much more effective than the traditional lecture-based format that is ubiquitous in STEM teaching today (see Section 2 of the Request for Proposals in the Appendix). Permanent change mandates department-level efforts, involving several faculty members in each department. This is expensive. Teaching with the new pedagogies is no more expensive than traditional lecturing, but the cost of converting from old to new is considerable. Experience at other institutions suggests a one-time cost of $1M to $2M per department, spread over 5 or 6 years, spent mostly on extra staff to help the faculty research, develop and test new materials, and to free them from other teaching obligations. We were helped at Cornell by a donor who was willing to launch the project with a cash gift of $2M.

$2M was not sufficient to fund full projects in all five of the college's STEM departments. Rather than fund several partial projects, we decided to concentrate funding on only one or two departments. We thought that a couple of large, well-funded projects were more likely to have lasting impact. Our goal was to establish viable efforts in a couple of departments, and then later to leverage change in other departments off the expertise developed by the pioneers. It also seemed important that the resources being offered at this stage were large enough to catch the attention of whole departments, making a department-level effort unambiguously worthwhile. We wanted significant changes in pedagogy and did not want lack of money to get in the way.

As a result of these considerations, we presented the project as a grant competition, for grants up to $1M per department spread over 5 years. We issued a Request for Proposals in September (see Appendix), with non-binding pre-proposals due at the end of October, and final proposals due at the end of the term in December. We emphasized that proposals had to come from departments as a whole, that participation was completely optional, and that any proposal had to be vetted by the entire department. By making competition optional, and requiring discussion and approval by the entire department, we hoped to identify departments who were genuinely enthusiastic about working on their teaching.

The dean announced the competition in a meeting with the STEM department chairs, and followed up in meetings with the individual departments that expressed interest. Despite the large amount of research on college-level STEM teaching (many hundreds of articles in physics alone, for example), most faculty are only vaguely familiar with the details and have a tendency to think that they are already implementing the best ideas from that research (or that the research is unreliable or ...). Few if any faculty have spent much time examining the literature on STEM teaching. Consequently an important early focus for us in launching our project was to help departments appreciate how radically different the new pedagogies really are, and how much more effective they can be.[1] The Request for Proposals attempted to address this by including several references to original research, as well as links to web sites, from similar efforts at other universities, containing detailed advice about implementation of new teaching strategies. We also brought in consultants from other institutions to work with individual departments, to help them create realistic and well-informed proposals. The consultants also helped us review the final proposals, looking especially for potential pitfalls.

The college also encouraged departments to leverage their proposals off resources available from the university's Center for Teaching Excellence, which has technical expertise in such things as the fine-grained assessment that is important to the new pedagogies. Another potential partner was the Graduate School, which is very interested in training graduate students to use modern pedagogies. Such training has important long-term implications for teaching at universities and colleges since most teachers at such institutions have Ph.D.s from research universities.

In the end, three of the five STEM departments submitted proposals, and the two most extensive proposals, coming from Physics and Biology, were selected. Both plans target large introductory course sequences, with hundreds of students each, and both involved large numbers of faculty (Physics, for example, proposed a team with six professorial faculty plus the chair, together with three senior lectures; Biology's group was larger). Both plans proposed phasing changes in over several years.

[1] See, for example, Deslaurier *et al*, Science 332, 862864 (2011). This article was covered in op-ed pieces in Science, the New York Times, and the Economist, among others. The Request for Proposals in the Appendix contains many additional references.

Potential Pitfalls

The proposal review process were designed to address a range issues and potential pitfalls, and led to the specific suggestions for the proposals including:

- A description of the process used for department-wide review and approval of the proposal. Department buy-in is essential if the innovations are to have any chance of outlasting the original project. Again it is not essential that every faculty member be enthusiastic, but the department as a whole has to agree that the project is worth a serious effort.
- A staffing and leadership plan, with the names of faculty involved, for the entire project period. The chair needs a detailed plan, and the faculty on the project team need to make long-range commitments to the project. Sabbatical and other leaves can wreak havoc absent a long-range plan and commitments —for example, the chair could be forced to assign one of the target courses to a faculty member who is not on the team and who isn't all that enthusiastic about the project.
- An explicit plan for rewarding faculty members who are heavily involved. Rewards (time and/or money) need to be significant, and best come after the work is done, since faculty members tend to overcommit and will likely need incentives to prioritize project work over other pressing demands in their lives.
- An instructor-independent procedure for comparing student learning before and after changes are made. This is obviously important for the morale of everyone involved, but needs to be thought through before changes are implemented so the "before" data can be collected.
- Plans for developing fine-grained (lecture-by-lecture) assessments of what students are learning. Information about how the students are dealing with the new teaching is particularly important early on, when there can be considerable push back from the students. (This push back can be mitigated to a considerable extent by taking care to explain to students what is being changed in the teaching and why.) Fine-grained assessment is an integral part of the new pedagogies.
- A plan for coordinating changes between different, related courses. For example, it is a good idea to change sequences one course at a time, in order, starting with the first course. Students who have been through a couple of semesters of, say, physics taught one way will often rebel if it is taught in a completely different way in subsequent courses. After one or two courses, many students feel they have figured out how to take a physics course, and so become very resentful if (they feel) the rules have been changed on them.
- A plan for archiving innovations and passing them on to new faculty outside the original project team, including plans for training new faculty

Conclusions

To sum up, important features of the Cornell project are: 1) its focus on department-level efforts, led by the chair; 2) its formulation as a competitive grant competition to attract the departments with the best ideas and strongest interest; 3) sufficient funding, for time and help, to enable the faculty involved to make significant changes in their pedagogy without heroic sacrifices in other aspects of their professional lives; 4) sufficient funding to attract the attention and sustained interest of at least some key departments; 5) personal involvement by the dean and department chairs, with department buy-in.

A further important feature of this project is that it was optional for individual departments. What a dean needs most in the early stages of a large-scale systemic change is enthusiastic partners who can help figure out what really works within the context of his or her particular college and university. This is most effective if the partners (departments) take ownership of their parts of the effort, if it becomes their project, not the dean's. This means that the dean should not mandate participation. It also means that the dean should not be overly prescriptive about the details of the project—ideally the departments are or will become far more expert than the dean on issues of modern pedagogy for their discipline.

The focus on departments and department chairs in the design of this project is an inescapable consequence of the administrative structure of the university. It also aligns well with the disciplinary specificity of much of the work on new pedagogies: many of the cognitive obstacles that hold students back are quite specific to particular subjects. There is also growing emphasis on teaching goals that focus less on the acquisition of particular facts and more on imparting an expert's facility with the subject through *deliberate practice* of expert thinking and performance. This kind of teaching requires deep subject expertise, and that resides in departments.

The dean's role in such an effort starts with finding resources. Multiple meetings with department chairs, first as a group and then individually, follow. These are used to generate excitement about the opportunities (created by the resources) and help focus early thoughts on the project's goals. Visits to departmental meetings underscore for the faculty as a whole the importance of serious department-level discussion of the project. Providing funds to allow departments to consult experts from outside—some suggested by the dean, others by the department—is important early on to help departments appreciate what is possible and what is realistic. Encouraging teams in different departments to interact with each other is also important, as you try to create a college-level community that is knowledgeable about modern pedagogy and committed to its implementation. Such communities are far more likely to form if the dean is actively involved, since, for one thing, the dean has the resources to help promote further efforts. Such communities will also be invaluable when the time comes to convince other departments to join the effort. The Cornell project was launched in September 2012 and will continue through 2018. It is much too early to tell how successful it will be, although early results have been encouraging. It is clear, however, that long-term success depends crucially upon the commitment and involvement of the deans and department chairs.

Request for Proposals: Sustained Improvement in Undergraduate Learning

G. Peter Lepage
For the College of Arts and Sciences and the Center for Teaching Excellence
September 2012

1: Overview

There is a substantial and growing body of research, both from cognitive psychology and from college-level STEM classrooms, that has identified several pedagogical approaches that are significantly more effective than the traditional lecture-based format used in most STEM teaching today. Motivated by this research, recent reports from the President's Council of Advisors on Science and Technology (PCAST),[1] and from the National Academies' study on Discipline-Based Education Research (DBER)[2] have called on universities and colleges to respond to the enormous opportunity that exists to improve college-level STEM teaching; and the Association of American Universities (AAU) has recently announced a major five-year initiative to improve STEM education.[3]

We have an opportunity at Cornell, if we act now, not only to improve undergraduate learning in our extensive STEM curriculum, but also to join the vanguard of an emerging national movement.

The College of Arts and Sciences, working with the Center for Teaching Excellence (CTE)[4], invites the college's STEM departments to submit proposals for funds to substantially improve large parts of their undergraduate teaching, particularly in large service courses or other core curricula. Funding is

1 *https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_2-25-12.pdf* Peter Lepage was a co-chair of the working group involved in this report.

2 *http://www.nap.edu/catalog.php?record id=13362*

3 *http://www.aau.edu/policy/article.aspx?id=12588* . Peter Lepage is a member of the Technical Advisory Committee for this initiative.

4 *http://www.cte.cornell.edu*

available for one or two grants of $500K-$1M each spread over 5-6 years. Departments interested in pursing these grants should send a (non-binding) 2-3 page pre-proposal electronically to Theresa Pettit, CTE director, at *tp64@cornell.edu* by Monday, 22 October 2012, outlining their initial thoughts about a proposal. Final proposals must be submitted electronically by Monday, 17 December 2012, and, ideally, are no longer than 15 pages. They will be reviewed by the college and CTE. Awards will be announced by Monday, 14 January 2012. Proposals will be evaluated on the extent to which they seek to exploit the new pedagogies to create widespread, sustainable improvements in a department's undergraduate teaching.

The remainder of this document details the kind of course redesign that we envision (see Sec. 2, which is bristling with clickable (blue) web links), as well as the presubmission and submission processes for this competition.

The funding for this project comes from a generous Cornell family.

2: Active Learning and Course Redesign

The new STEM pedagogies emphasize student-centric practices that stress active learning, with much more interaction among students, and between students and instructors than in the traditional lecture-based format, even when applied to large classes in traditional lecture halls. These methods emphasize building a course backwards from carefully articulated learning goals for both the course as a whole and also broken down into specific sub-goals for every lecture. The goals are less about the acquisition of particular facts, and more about imparting an expert's facility with the subject through *deliberate practice* of expert thinking/performance.[5] These methods generally incorporate fine-grained, real-time assessment of student learning in relation to the learning goals—information that is essential to the students themselves as they grapple with the course material.

The new pedagogies go far beyond simply adding clicker questions to a traditional lecture, as illustrated by a recent study featured in the PCAST report, and published in *Science*. This paper describes a controlled experiment in week 12 of an 850-student course in second-semester introductory physics: see *Deslaurier et al, Science 332, 862-864 (2011)*. The experiment examines the impact of replacing conventional lectures by a variety of in-class small-group learning exercises, with instructor feedback but no formal lecturing. In both the experimental and the control groups, students are taught in groups of 270 students, in large lecture halls. The experimental approach yielded

[5] The emphasis on deliberate practice stems from recent research indicating that the extent to which students engage in such practice is more important to their ultimate success than their *a priori* proclivity for the subject. This is contrary to conventional wisdom about STEM teaching, much of which has functioned in the past as a filter for selecting people with an *a priori* proclivity. For a popular account of the research see the article by *P. E. Ross in the August 2006 Scientific American (vol. 295, 64-71)*; this has references to the scholarly literature.

much higher achievement for students across the entire spectrum of student achievement, as shown by Fig. 1 of the paper—the entire distribution of outcomes is shifted up by more than two standard deviations. This example is interesting because it describes a set of apparently quite effective pedagogical moves that do not require small or specialized classrooms, and that do not require additional staff, since the class size is unchanged.

Another study, also from *Science*, examines how student interaction in the classroom can affect learning in a large genetics class: see *Smith et al, Science 323, 122-124 (2009)*. A very recent study, reported in *Science*, uses more than 111,000 student records in a large introductory biology course to show how active learning strategies disproportionately benefit students from educationally disadvantaged backgrounds, shrinking the achievement gap for this group: see *Haak et al, Science 332, 1213-1216 (2011)*.[6]

These are just a few examples from a now extensive literature on discipline-based education research. One source for additional literature is the recent NSF-funded project commissioned by the National Academies on Discipline-Based Education Research (DBER), mentioned in the Overview. There is a report and also a series of commissioned papers which include annotated literature surveys for several disciplines[7]—the physics survey, for example, has more than 500 references. Another recent resource letter for physics, but with information that is broadly applicable (in the introduction), is *Metzler and Thornton, Am. J. Phys. 80(6), 478-497 (2012)* .

Our grant competition is modeled closely after similar competitions run by the Science Education Initiatives at the University of British Columbia (CWSEI) and at the University of Colorado at Boulder (SEI).[8] These initiatives have extensive web sites containing lots of material that should be useful in preparing proposals: see *http://www.cwsei.ubc.ca* and *http://www.colorado.edu/sei* . In particular, our request for proposals is modeled after theirs (but contains less background material): compare *http://www.cwsei.ubc.ca/about/CWSEI_RFP_summer_2007.pdf*. The winning proposals at UBC and CU can be found at *http://www.cwsei.ubc.ca/ about/funding.htm* and *http://www.colorado.edu/sei/about/funding.htm* .

The UBC website provides detailed information about course transformation that should help clarify what is involved: see *http://www.cwsei.ubc.ca/resources/other.htm#transform* . The documents there include:

- *SEI Suggested Indicators for Full Implementation,* a concise description of what needs to be accomplished for a complete implementation of a course redesign;

6 The achievement gap under discussion is clearly visible at Cornell.

7 *http://sites.nationalacademies.org/dbasse/bose/dbasse_072106*

8 These initiatives were both founded by Carl Wieman, a Nobel-Prize winning physicist who has spent most of the past decade working on STEM education, including as the Associate Director for Science in the White House's Office of Science and Technology Programs from September 2010 to June 2012.

- *Course Transformation Expectations,* a checklist and timeline for tasks involved in a course transformation;
- *STLF-Faculty Interaction Model*, a model for how faculty and teaching postdocs (STLFs) can collaborate on course redesign; teaching postdocs, who play a critical role in CWSEI initiatives, are recent Ph.D.s in the discipline, with a strong interest in education, who review the teaching literature and work with faculty to implement novel instructional practices and assessments of learning;
- *Course transformation case study*, a very detailed account of the course transformation process for a mid-level undergraduate quantum mechanics course at Boulder.

There are additional links to published articles with overviews of the processes involved and the thinking behind them.

The UBC site also has a collection of short guides—on assessment, clicker use, student engagement, *etc., etc.*—that illustrates in more concrete terms the pedagogical philosophy (active engagement of students) underlying these initiatives: see *http://www.cwsei.ubc.ca/resources/instructor_guidance.htm* . If you prefer to watch videos visit *http://www.cwsei.ubc.ca/resources/SEI_video.html* . For a sampling from the background literature on the subject visit *http://www.cwsei.ubc.ca/resources/papers.htm* .

3: Presubmission Process

We have a moderately structured presubmission process to help departments develop successful proposals. This process has five ingredients:

1. Peter Lepage is available to discuss this competition with chairs and departments throughout much of the presubmission period.

2. Departments must submit (non-binding) pre-proposals by Monday, 22 October 2012. These will help the college and CTE design subsequent stages in the presubmission process, and, more importantly, allow them to give detailed advice to departments on how they can enhance their proposals. The pre-proposals need only be 2-3 pages long, and should indicate the department's initial thoughts about what they want to change in their curriculum, how they might do it, and why. It is essential that any proposal ultimately be endorsed by the department faculty as a whole, following a substantial discussion (one or more entire faculty meetings). A significant part of this discussion should precede the pre-proposal. Email pre-proposals to Theresa Pettit at *tp64@cornell.edu* . *The pre-proposal is not binding and will have no bearing on the final award decisions.*

3. Departments should have faculty who are currently teaching the courses relevant to their proposal fill out a Teaching Practices Survey.[9] This is a short (5 minute) online survey, developed at UBC, about how faculty teach their courses. This will provide the department and college with benchmark information.

4. In addition to talking with the dean, departments are encouraged to meet with CTE and the Learning Strategies Center (LSC) to explore how their proposals might utilize and/or coordinate with existing resources in these programs. Contact Theresa Pettit (*tp64@cornell.edu*) for more information. Also the Graduate School has launched a major new effort — the Center for the Integration of Research, Teaching, and Learning (CIRTL)[10] — to advance teaching in STEM disciplines through better training of graduate students. Departments should contact Colleen McLinn (*cmm252@cornell.edu*), CU-CIRTL's director, to discuss how CIRTL's training of their graduate students might be coordinated with the department's course redesign.

5. We have arranged for Carl Wieman and Sarah Gilbert, the founding director and acting director of the CWSEI program at UBC, to visit Cornell on November 15 and 16. They will spend their time here consulting with individual departments on the department's proposal. They will have read the department's pre-proposal and the results of the department's teaching-practices surveys. We are scheduling these meetings late in the process so that departments will be fairly advanced in their proposal writing, and so can have detailed discussions about specific issues with their consultant

Finally the college has (limited) travel funds available for departments to bring other consultants to campus or to send faculty to visit programs elsewhere. Department chairs should contact their senior associate deans with requests.

4: The Proposal

We expect proposals to outline plans for overhauling specific courses in response to department-wide discussions and agreement on detailed, measurable education goals for each course—that is, agreement on what students are expected to be able to *do* after taking each course. Such plans should sketch strategies for rigorous evaluation of what students actually learn in each course; and they should detail the process for introducing and developing the materials, curriculum, and teaching methods required to improve the quality of instruction. Changes should be grounded in existing education research as much as possible.

Teaching with the new pedagogies should be no more expensive than

9 *https://www.cte.cornell.edu/documents/presentations/Active%20Learning%20-%20Creating%20Excitement%20in%20the%20Classroom%20-%20Handout.pdf*

10 *http://www.gradschool.cornell.edu/cu-cirtl*

traditional teaching, but the cost of converting from old to new can be considerable. The grants in this competition are meant to cover this cost. The major cost in such conversions is typically extra staff, and, in particular, teaching postdocs whose support makes it feasible for active faculty members to participate (see above).

Each proposal should include:

- a leadership/oversight plan for the entire project;
- a list of courses being changed, the rationale for changing these courses, and the changes that are being contemplated;
- a timeline for changing courses that identifies specific courses and the corresponding instructor staffing plans (including instructor names) for those courses over the life of the grant;
- an instructor-independent method for comparing student learning in previous years with learning subsequent to the changes (*e.g.*, concept tests, or suitable questions from old exams that can be carried over in isomorphic variations);
- a discussion of the extent of and mechanisms for faculty involvement, including the ways in which faculty effort will be recognized/rewarded;
- plans for coordinating change within course sequences, and achieving coherence across the department's entire undergraduate curriculum;
- plans for transferring transformed courses to new instructors without losing the educational improvements;
- a description of the process used for department-wide review and approval of the proposal;
- a description of any collaboration that involves CTE, LSC, CIRTL, or other similar groups at Cornell in the course redesign;
- an approximate budget, by expense category.

Final proposals are due by Monday, 17 December 2012, and ideally are no longer than 15 pages. Email them to Theresa Pettit at *tp64@cornell.edu*

Case Study 5

Lyman Briggs College: An Environment Supporting Change

Elizabeth H. Simmons, Dean, Lyman Briggs College
Ryan Sweeder, Associate Professor, Lyman Briggs College

Introduction

Michigan State University's Lyman Briggs College[1] (LBC or Briggs) is a residential degree-granting undergraduate college devoted to studying the natural sciences in their historical, philosophical, literary and social context. All under one roof, LBC includes science laboratories and classrooms; faculty and advising offices; and residential and dining facilities. Briggs offers its 1,900 students the best of both worlds: the close-knit residential community of a liberal-arts science college combined with the resources of a great research university. For 50 years, Briggs has helped prepare liberally educated scientists who understand the fundamental scientific and mathematical context of their disciplines and also appreciate the societal context of science.

LBC creates a learning environment that helps students develop into high achieving science graduates. Reflecting MSU's land-grant values, the student body is diverse, including 60% women and 20% students of color; entering freshmen range from the 20% who qualify for MSU's Honors College to the 15% who are not ready to take pre-calculus. The college has a 95% rate of retention to the 2nd year and a 6-year degree completion rate of 85%. Over 72% of entering LBC students complete STEM degrees at MSU, as compared with 40-50% of entering STEM-interested students nationally; approximately 80% of Briggs alumni pursue post-graduate degrees, nearly all in STEM and about half in medical fields.

The college achieves these outcomes by using research-validated instructional methods to actively engage students in the process of science

[1] *http://www.lymanbriggs.msu.edu*

through its introductory science and mathematics courses and in the human context of science through a four-year curriculum in the history, philosophy, and sociology of science (HPS). Also important are the college's interdisciplinary approach to teaching and scholarship and the high rate of faculty participation in the Scholarship of Teaching and Learning. These elements[2] have made Lyman Briggs an ideal place to test teaching innovations for later dispersion across the other MSU STEM colleges.

Aspects of the practice and culture in Lyman Briggs serve as useful models for STEM departments or colleges that are interested in transforming their STEM gateway programs. This case study focuses on two examples: (a) a faculty environment that rewards an experimental and scholarly approach to teaching and (b) faculty-led creation of an inclusive on-ramp program that helps freshmen with low math placement scores succeed in STEM majors.

A Culture Conducive to Change

The Lyman Briggs College faculty—active and accomplished scholars whose primary focus is undergraduate education—span the sciences from astrophysics to zoology and also fields in the history, philosophy, and sociology of science (HPS). What binds the faculty together is their common interest in sustaining a strong, effective Briggs curriculum, their investment in collaborative interdisciplinary approaches to research and teaching, and their incorporation of research-validated teaching methods into student-centered classrooms. Crucially, this culture runs much deeper than individual faculty members' contributions to the design and execution of LBC courses; it is also reflected in the college's faculty evaluation processes, peer mentoring practices, governance, and allocation of resources.

The evaluation[3] of faculty for annual merit raises or promotion and tenure stresses excellence in teaching, including a scholarly approach to education. Reviews draw on a variety of evidence, including student evaluations, faculty self-evaluations, teaching portfolios, and peer assessment. Accomplishments in the Scholarship of Teaching and Learning or Disciplinary Based Education Research, including publications, presentations, grants, and awards, are also included. Student evaluations, including extensive written comments, are collected every semester. Faculty members must reflect upon their courses in writing every year to consistently monitor their teaching effectiveness. Each faculty member also has a review committee of one or two other faculty members who yearly perform class observations. Lastly, most faculty members maintain teaching portfolios as a means for demonstrating the efficacy of their courses in promoting learning. Key documents that guide

[2] For further details, see "Lyman Briggs College: An Innovative Living-Learning Community for STEM Education," R.D. Sweeder, K.A. Jeffrey, and A.M. McCright, *Quality Approaches in Higher Education*, Vol. 3, No 2., Pg. 7. December 2012.}

[3] *http://www.lymanbriggs.msu.edu/faculty_staff/AppointmentsPromotionsCareers.cfm*

faculty review are included in the Appendix.

The college employs research-validated instruments to assess and evaluate teaching. Briggs formally adopted the Student Assessment of Learning Gains (SALG)[4] in 2011 as the primary means for collecting students' feedback about their course experiences. The SALG asks students to evaluate their improvement on specific skills, abilities, or knowledge. It shifts the assessment of the classroom from "teaching" to "learning" and better addresses the key attribute in the efficacy of classes: what students learned. Similarly, faculty employ the Reformed Teaching Observation Protocol (RTOP)[5] to assess the kind of learning environment that an instructor fosters within the classroom. This instrument provides a resource for mentoring committees and facilitates the practice of openly discussing challenges encountered in promoting student learning.

Lyman Briggs embraces a culture of experimentation. Whether or not a teaching innovation lived up to expectations, faculty are expected to discuss the aims, methods, outcomes, and future of that innovation in their annual self-evaluations. Peer mentors draw on those essays to advise faculty about their teaching methods, including how to help students understand the benefits of the active-learning pedagogies that require more effort from them. This creates an atmosphere in which faculty feel safe in attempting to broaden their teaching repertoires and discussing these efforts with peers. As a result, much of the college's work to incorporate active learning and authentic inquiry throughout the curriculum has been undertaken by a host of faculty-initiated collaborations that often span multiple years, courses, and disciplines.

Indeed, the college fosters interdisciplinary approaches across the mission. All governance functions, from faculty searches to educational policy making, are carried out by cross-disciplinary teams. Office locations are assigned to ensure that faculty will routinely encounter colleagues from other fields in the hallways. Faculty are encouraged, via curriculum development funds and credit in annual evaluations, to collaborate on course materials, assessments, and entire courses that span disparate fields. Much of this work is supported by external grants, and the college funds pilot studies to seed new external grant proposals. Briggs also hosts national conferences on interdisciplinary teaching and learning to highlight local accomplishments while engaging faculty in the broader conversations on these topics.

More generally, Briggs supports faculty efforts to develop approaches to teaching and learning that can be implemented in other settings, and disseminate these approaches across campus and beyond. Within the college, funds are provided for individuals or teams to present at teaching-focused conferences; faculty are nominated for local and national cohort programs in

4 *www.salgsite.org*

5 *http://physicsed.buffalostate.edu/pubs/RTOP/RTOPTrgGd_IN002.pdf*

the scholarship of teaching and learning; and education-related publications are valued in annual and promotion reviews. At the campus level, Briggs has cofounded an MSU Undergraduate STEM Education Alliance that unites the four undergraduate STEM colleges in offering Teaching Essentials workshops for STEM faculty and reforming the teaching of introductory courses across all STEM disciplines, with the support of substantial external grants.

All of these elements combine to create an environment where faculty know that it is safe to try new approaches to teaching, colleagues welcome discussions about pedagogy, and taking a scholarly approach to education is rewarded. This is a culture where educational innovation and assessment are flourishing at every scale, from individual class to college-wide curriculum.

An Inclusive Curriculum

In recent years, the LBC faculty have created a multidisciplinary curriculum called INQUIRE (Instilling Quantitative and Integrative Reasoning) to improve retention in STEM courses and majors by students who enter college with low mathematics proficiency, as measured by the MSU mathematics placement exam taken by all incoming freshmen. Since most of these students are also students of color, first-generation in college, or from under-served school districts, this program helps keep more students from traditionally under-represented populations in STEM. This section of the case study offers a historical account of the development of INQUIRE to highlight the iterative, self-reflective process needed for implementing successful curricular change; some current INQUIRE materials are in the Appendix.

Before INQUIRE was created, students entering with low math proficiency were much less likely than their peers to succeed in their first science courses within LBC and persist in STEM majors. Because their mathematics placement score prevented them from taking chemistry as freshmen, they were placed in Biology I, a course largely populated by sophomores with a year's college experience and a year of college chemistry behind them. Over time, the faculty noticed that these freshmen were not performing well in Biology I; their average course grade was more than half a point lower on a 4-point scale than that earned by sophomores (2.25 vs. 2.85). In response, the biology faculty began offering the freshmen supplemental instruction, including faculty-led laboratory sections; unfortunately, their academic success and retention did not improve.

In 2009, the biology faculty joined with the chemistry faculty and the LBC academic advisors to create a fresh approach for this student cohort: an on-ramp course, LB155 (Introduction to Quantitative Science and Research). The course covers key topics in biology and chemistry, integrates mathematical concepts alongside their scientific applications, and includes experiential learning. Class meetings employ a combination of mini-lectures and individual- and group-based active learning exercises to offer students real-time practice with newly learned concepts and techniques. In the laboratory, the students perform open-ended inquiry-based experiments, for instance in isolating bacteriophages from soil samples. The instructors are explicit about creating an inclusive learning environment, developing a supportive community, and building skills that promote success in the college classroom and scientific careers. The pilot offering of the course used an opt-in model; once the course's value was established, the college switched to an opt-out model and 95% of eligible freshmen now take LB155 (about 80-90 students).

Initially, students who took LB155 in the fall of freshman year moved into Biology I in the spring. To assess whether this sequence met students' needs, the college compared the academic progress of freshmen with low math placement scores who either (a) took LB155 before Biology I, or (b) did not take LB155 but were given supplemental instruction during Biology I, or (c) took Biology I without either LB155 or supplemental instruction. While the data showed that LB155 did help students succeed in subsequent science courses, the gains were modest.

Given that students who choose to enter Briggs are highly motivated and hard working, the faculty believed it should be possible for the students with lower math placement to perform comparably to their peers. So the team joined forces with the mathematics faculty to create the current INQUIRE program that includes courses in mathematics, biology, and chemistry, close work with dedicated faculty and advisors, research experiences, and opportunities to serve as peer learning assistants. The presence of learning assistants who are recent successful alumni of the LB155 course has been found to give the current cohort a strong confidence boost.

INQUIRE opportunities now begin even before students matriculate. The program's math and chemistry faculty members serve as academic advisors during the pre-freshman summer Academic Orientation Program; hence, INQUIRE students encounter familiar faces in the classroom at the start of fall semester. Lyman Briggs has also recently partnered with other MSU STEM colleges to create residential and hybrid summer bridge programs intended to boost students' math preparation before freshman year. Students completing the bridge programs generally place at least one course higher upon retaking the MSU math placement exam. The college anticipates this will further improve retention and decrease time to degree.

Freshmen entering INQUIRE take a newly created algebra course taught in-person by Lyman Briggs math faculty along with the on-ramp science course, LB155, in the fall semester. Like all Briggs freshmen, they also take the college's required introduction to the history, philosophy, and sociology of science, which includes a strong focus on writing. In spring semester, they proceed to the next higher mathematics course and often take a general education course in the humanities or social sciences. However, as students intending to major in a STEM discipline, they must also take a science course in spring.

INQUIRE students initially had to either take the university's large Chemistry I course in the spring or wait till sophomore year to begin Briggs's chemistry sequence (and take biology in the spring of freshman year). Yet the Briggs chemistry faculty noticed that the INQUIRE students were performing well below other students in both versions of Chemistry I. In response, the faculty made two changes to the INQUIRE curriculum. First, they began addressing students' study skills and self-efficacy explicitly in LB155; for example, they started using old exam questions from Chemistry I as in-class exercises during LB155 and pointing out the source of the questions after students had completed them successfully. Second, they began offering Chemistry I in the spring semester for the INQUIRE students, to maintain the cohort experience and enable the students to follow the usual chemistry-before-biology science sequence. The outcome was impressive: the Chemistry I grade distribution (mean and standard deviation) earned by the INQUIRE students is now identical to that for typically prepared freshmen who take Chemistry I in fall. In response to this finding, the college has opened an INQUIRE section of Chemistry II in fall semesters. Since the Briggs biology courses are offered both fall and spring, the INQUIRE students can move promptly into the biology sequence, now with the same preparation as the other students in the course.

Initial data on long-term progress of the INQUIRE students shows that their persistence in STEM majors is rising from 20 points below the LBC average towards parity. Together with MSU's Learning Analytics Group, the college is preparing to thoroughly study the influence of the INQUIRE curriculum (including the summer bridge) on students' later success in courses required for STEM majors, as well as their overall retention and STEM degree completion rates.

Final Thoughts

The approaches that Lyman Briggs College employs are not only conducive to the reform of curricula and courses, but they also directly improve student learning. By stressing scholarly approaches, experimentation, interdisciplinarity, collaboration, and inclusive practice in teaching and learning, Lyman Briggs engages students in the very behaviors it wants them to acquire for their future careers. As participants in science, the LBC faculty know that ideas and methods can only be evaluated through real world experimentation and analysis. Thus, they actively bring students into the experimental process not only in the laboratory, but also in the classroom. They encourage students to think critically about teaching and learning as a means to further develop their understanding of the scientific process. Recognizing that students who will eventually become instructors are most likely to "teach as they were taught," the LBC faculty strive to include student-centered classroom practices, not only to improve student learning, but also to influence future educators. This idea also is applicable well beyond Lyman Briggs, and is a key reason for promoting the use of research-validated approaches throughout undergraduate STEM education nationwide.

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