Re-looking Undergraduate STEM Education

Reform at Brown University

An Undergraduate Thesis in Science and Technology Studies

Elizabeth Schibuk

April 2008
Acknowledgements

Thank you to my advisor, Anne Fausto-Sterling, for providing such thorough feedback.

Thank you to my second reader, Larry Wakeford, for agreeing to be my second reader during his last semester at Brown.

Thank you to my surrogate thesis advisors, Dean Robin Rose and Kathy Takayama, for helping me along the way.

Thank you to my mum, for teaching me how to write.

Thank you to Joan Richards, Jan Tullis, and John Stein, for talking with me about science education.
Table of Contents

Chapter 1: Introduction to Science Education Reform at Brown University..............4

Chapter 2: The History of Undergraduate Science Education Reform...............33

Chapter 3: Evaluating Brown’s Undergraduate STEM Reform Effort..................68

Chapter 4: Reworking Scholarship.................................................................95

Conclusion.................................................................................................112

Appendix 1: Glossary.........................................................................................124

Appendix 2: PBL at University of Delaware....................................................126

Appendix 3: Sample Research Protocol.........................................................135

Bibliography.................................................................................................139
Chapter 1

Introduction to Science Education Reform at Brown University

According to the 2005 Survey of the American Freshman, the longest running survey of student attitudes and plans for college, approximately one-third of all incoming freshmen have traditionally contemplated a major in a science and engineering field, with most intending to major in a field of natural or social science and a smaller percentage selecting mathematics, the computer sciences, or engineering. Yet, half of all students who begin in the physical or biological sciences and 60 percent of those in mathematics will drop out of these fields by their senior year, compared with the 30 percent drop out rate in the humanities and social sciences.

- US House of Representatives

Introduction

Approximately 50% of students who enter college in the United States with an interest in science end up completing their undergraduate degree in the sciences (US House of Representatives 3). Undergraduate science, technology, engineering, and mathematics (STEM) education is a topic of national concern. Uninspired curricula, inaccessible courses, and insufficient professor support for students are all pressing issues with contemporary undergraduate STEM education. Student attrition from the STEM disciplines is a problem at institutions of higher learning across the country, and educational researchers continue to investigate how to better attract and retain students in
the STEM fields. While many talk about the issue of maintaining undergraduate interest and persistence in the STEM fields, numerous stakeholders hold a wide range of opinions on how to best address these problems.

Brown University has not remained immune to the problem of student dissatisfaction with undergraduate STEM programs. While interest groups have begun to investigate the nature of undergraduate STEM education at Brown, few of the recent internal reports on this subject reference the pertinent history, theories, and research on undergraduate STEM education reform.

This thesis summarizes the recent efforts to improve undergraduate STEM education at Brown University, and then analyzes these reform efforts in light of the last half-century of literature on undergraduate science pedagogy and education reform. Reformers cannot fix that which they do not understand. Properly addressing the issue of undergraduate STEM education at Brown requires thoroughly understanding the history and the scope of the issue. With a grounding in the recent history and literature on undergraduate STEM education, I hope to clarify which areas of Brown University’s recent recommendations for improving STEM education are well grounded in relevant research and theory, and then to identify the recommendations for undergraduate STEM education improvement that warrant further attention, research, and revision. I end with suggestions for further research and action, combining our knowledge of the history and research relevant to this problem with our understanding of the particular needs, cultures, and goals of Brown University. Here follow the list of questions that I explore in this thesis:
1. What are the concerns with undergraduate STEM education at Brown?

2. How have students, faculty, and administrators been looking to address these concerns?

3. Are these concerns unique to Brown?

4. What have experts and interest groups outside of Brown said about undergraduate STEM education and education reform?

5. How does the answer to question 4 inform our understanding of STEM education and education reform efforts at Brown?

6. What’s the next step in helping to improve undergraduate STEM education at Brown?

One common criticism of STEM education reformers is that they often try to solve too many problems at once, doing at best a mediocre job of properly fleshing out any one problem. In my research, I have encountered a striking variety of opinions on the state of undergraduate STEM education both at Brown and throughout the United States. Not only do people seem to have differing understandings of contemporary undergraduate STEM education, but they harbor a wide variety of opinions both on what the ideal undergraduate STEM program would look like, and on how to achieve their ideal. The one issue that seems to elicit near consensus is the problem of attrition. While there exist many opinions on the best ways to retain students in STEM fields, most reformers at least share the hope that more students with an interest in science will not abandon STEM programs. To set the parameters for my understanding of “success” throughout this thesis, I focus on the issue of student retention and borrow Sheila Tobias’ definition of a successful undergraduate program - one with “successful recruitment of
students; a high rate of retention of those crossing the introductory threshold; and student
and faculty morale” (Tobias 12).

STEM reform at Brown

The story of contemporary undergraduate STEM education reform at Brown
begins with the development of the Plan for Academic Enrichment, launched by the
Office of the President and approved by the Corporation in February 2002. In April
2003, the Office of the President published a report outlining the guiding principles that
would guide the University’s long-term plan for academic enrichment. The report,
“Initiatives for Academic Enrichment,” (Brown University, 2003) states its purpose as
follows:

While Brown is today a preeminent University, we are obliged to take
decisive steps now to ensure that Brown is even stronger in the future.
The document that follows expresses in outline form a set of initiatives
that will help us achieve that goal. It also describes what we must do
today and over the next 10 to 15 years to make that vision a reality.
(Brown University, 2003, 3)
The report covers 6 strategic goals for enriching the academic experience at Brown in the
coming years. While none of these is exclusively dedicated to the topic of undergraduate
STEM education, three of the six recommendations inform our discussion. The relevant
recommendations are (Brown University, 2003, 6):

1) Faculty Excellence in Teaching and Research
2) Enhancing Brown’s Undergraduate Education

5) Fostering Multidisciplinary Initiatives

Now, five years down the road, it is possible to begin to look at how the broad goals outlined in this initial Plan for Academic Enrichment report have begun to take shape and how they have informed recent efforts to improve undergraduate STEM education. Here follows a description of the three most recent efforts to address issues with undergraduate STEM programs at Brown: the Science Cohort (2005-2006), the Undergraduate Science Education Committee (2006-2007), and most recently the Task Force on Undergraduate Education (2007-2008).

The Science Cohort

The push to improve undergraduate STEM education at Brown began sometime in 2005 with the Science Cohort Committee. There are few public records about the Science Cohort Committee, and so it remains unclear precisely who served on this committee and when the committee was active. Brown Daily Herald articles indicate that former Dean of the College Paul Armstrong and Provost Robert Zimmer were at least two of the administrators serving on this committee, while Faculty Meeting minutes from October 2005 indicate that Professor Tom Dean headed the committee.

The Science Cohort Committee sought new ways to “attract the nation’s top science undergraduate students from diverse backgrounds” (Rockland-Miller). The Brown Daily Herald quotes Paul Armstrong: “I think that Brown is really an exciting
place to come and do science just to begin with, but I do not think we’re perceived that way by high school seniors” (Rockland-Miller). The article continues to express that Brown would like to be a leading university for the sciences and perceives itself as competitive with specialized STEM schools like Cal Tech, and that the university has to find ways of convincing top science students of this reality.

In the Fall semester of 2005 and again in the Spring semester of 2006, the Science Cohort Committee proposed a tentative Science Cohort program (later renamed the Integrative Science and Engineering Program) to the faculty. The Science Cohort would be a specialized interdisciplinary science degree program that would admit 60 students per year. Science Cohort students would be guaranteed two summer Undergraduate Teaching and Research Awards (UTRAs) to subsidize summer research projects following students’ sophomore and junior years. The program would also require students to take three team-taught introductory courses focusing on multidisciplinary science, followed by two upper level multidisciplinary science courses. Building off this multidisciplinary foundation, Science Cohort students from different science disciplines would team up for a multidisciplinary capstone project. The Brown Daily Herald writes that this capstone project “would simulate real world interactions of scientists, and the objective would be to ultimately produce publishable material” (Rockland-Miller).

There is scarcely any public information on either the Science Cohort committee or on the plans for the Science Cohort program itself. The university’s main student newspaper, the Brown Daily Herald, appears to be the only publicly available source of information about the Science Cohort proposal. Faculty meeting minutes, which are available online (http://facgov.brown.edu/meetings/facmeetingmin.html), also make
occasional reference to the proposed Science Cohort program. The faculty meeting
minutes do not, however, explain in detail the purpose or content of the program, nor do
they detail the faculty discussions about the program.

The limited resources detailing the Science Cohort Committee’s work and the
faculty discussions on the proposed Science Cohort program make it challenging to know
precisely why university administrators abandoned the program and when the Committee
was dissolved. Brown Daily Herald articles suggest that the Science Cohort proposal was
abandoned in the late spring of 2006 due to strong faculty opposition. Even though the
university may have abandoned the proposal for a Science Cohort, the university by no
means abandoned the issue of STEM education. One Brown Daily Herald article reports
that it was “in wake of the strong faculty opposition” to the Science Cohort proposal that
the university formed the Undergraduate Science Education Committee in late 2006.

*The STEM Committee*

In October of 2006, the Dean of the College and the Provost of Brown University
drew together the Undergraduate Science Education Committee (the STEM committee).
While administrators launched the STEM committee in response to faculty opposition to
the Science Cohort, they also drew together the STEM committee in the larger context of
moving forward with the Plan for Academic Enrichment. As part of the Plan for
Academic Enrichment’s second strategic goal – Enhancing Brown’s Undergraduate
Education – administrators charged the STEM committee with the task of investigating
the state of undergraduate STEM education at Brown University. Their mandate was “to look broadly at the quality and effect of our science curriculum and to make recommendations for innovation and improvement” (USEC 31). Reflecting upon the controversial Science Cohort, the STEM committee chair, Karen Fisher, expressed her goal for the committee as such: “I hope that this committee will be able to organize a better picture of what science is like here [at Brown] to put a very clear image of the work that’s being done here” (Park). Karen Fischer made a point of highlighting that the STEM committee will be entirely distinct from the previous Science Cohort committee. The Brown Daily Herald reports that, in juxtaposition to the Science Cohort proposal, “the mission of the [STEM] committee seemingly invites a thorough review of Brown’s existing math and science offerings before suggesting opportunities to improve upon them” (anonymous 10/31/06). The STEM committee also differed from the Science Cohort committee in that the STEM committee was seeking to “make sure our science courses are meeting the needs of students across the University” (Park) rather than only serving a minority elite – a major criticism of the Science Cohort program proposal.

Twelve faculty members served on the STEM committee and eight undergraduates served on the affiliated student steering committee. Nine of the ten faculty on the committee hold an appointment in a STEM discipline. The tenth faculty member, Tara Nummedal, holds her appointment in the History department, while also holding a place on the Committee on Science and Technology Studies (COSTS). The two remaining faculty members, David Targan and Pamela O’Neil, are university administrators with science backgrounds. In total, eleven of the twelve faculty on committee came from the sciences. Seven of the eight students on the undergraduate
steering committee were concentrating in STEM disciplines, and the eighth was a Science and Technology Studies concentrator. The dominant science contingent of the STEM committee was not a coincidence, as it was specifically part of the Dean of the College and the Provost’s charge that the committee be composed of a “group of faculty representing a broad spectrum of math and science disciplines” (USEC 31). Of further note regarding the composition of the STEM committee, all of the professors held one of the following three job titles: assistant professor, associate professor, or professor, all of which are tenured or tenure track positions.

The STEM committee split into four sub-committees according to four identified issues in undergraduate science education – curriculum, undergraduate research, advising and retention, and admissions and recruitment. While all four of these issues work together to dictate the quality of undergraduate STEM education, here I will primarily discuss the issues of curriculum and retention as they are most directly tied to our discussion of improving the quality of undergraduate STEM education.

The committee’s investigation culminated with a report to the Brown community, published in June of 2007. The STEM report begins by noting that “retention of students in STEM fields is a concern” (USEC 5). According to data collected between 2000 and 2005, only 64% of students initially indicating an interest in STEM disciplines will complete a concentration in a STEM field (USEC 5). Brown’s open curriculum allows students to dabble in numerous disciplines in a manner that might influence their concentration interests and potentially explain the 34% of students leaving STEM fields. The open curriculum and liberal arts structure of Brown’s degree programs might explain
these high attrition rates if there were equal percentages of students entering and leaving the STEM concentrations, and yet no such equilibrium exists. Far fewer students belatedly enter STEM concentrations than leave them (USEC 5-6). These statistics indicate that disproportionate attrition from STEM programs is a real problem, and one worth investigation.

Given the high percentage of students leaving STEM disciplines and the STEM committee’s interest in improving the quality of undergraduate STEM education, the committee begins by addressing what is happening in the science classroom. Since students who do abandon their interests in STEM concentrations do so early on in their time at Brown, the committee focused their attention on introductory science courses, which they describe as “key to access and retention in the STEM fields” (USEC 1). With a desire to “enhance curricular innovation that keeps pace with the forefront of scientific inquiry” (USEC 6) and “to bring more research-style or project-based experiences into courses,” (USEC 6) the committee maps out three main areas for reform: multidisciplinary courses, project-based learning, and teaching science across the curriculum. These reforms hope to “provide engaging and accessible courses that [would] improve an understanding of science among undergraduates in all fields” (USEC 7).

The first suggested curricular reform is the development of multidisciplinary courses. The STEM committee does not, however, properly define their understanding of the term multidisciplinary and it remains unclear whether they envision these new multidisciplinary courses to be building bridges between multiple scientific disciplines or between the STEM disciplines and the humanities and social sciences. The committee’s
survey to undergraduates asked students what sort of science class students would be most interested in taking: group laboratory techniques courses, conceptually-based science courses, or interdisciplinary science-humanities courses. In this question, interdisciplinary is clearly meant to describe the merger of STEM and non-STEM fields. Of the three options that the committee proposed, 51% of students expressed an interest in interdisciplinary science-humanities courses, compared to only 25% with an interest in group laboratory techniques courses and 24% with an interest in conceptually-based science courses (USEC 40). Despite this strong interest in interdisciplinary science courses, “students are not immersed in multidisciplinary thinking at an introductory level” (USEC 8). This lack of multidisciplinary science courses at the introductory level may be a key issue if students are leaving the sciences at the same time that they are generally taking the introductory courses. When the committee talks about models of successful introductory level interdisciplinary courses that peer institutions have developed, however, they reference courses that bridge multiple scientific disciplines and not courses that aim to bridge scientific disciplines with the humanities or social sciences. The report presents the following examples of multidisciplinary STEM courses (USEC 8):

Multidisciplinary courses at the introductory level are being developed at several of our peer institutions. Particularly successful examples include Life Sciences 1a at Harvard, Frontiers of Science at Columbia, and an intensive course for freshmen at Princeton that blends biology, physics, chemistry, and computation.
The STEM committee’s selection of model multidisciplinary STEM courses is an example of the way in which they are conflating two separate issues: they are responding to students’ desires for more multidisciplinary science-humanities courses by referencing courses that blend different STEM disciplines, but not courses that blend the sciences and the humanities. The STEM report clearly highlights the need for more multidisciplinary programs, but the report does not parse out two somewhat distinct needs: more integrated science courses and more truly multidisciplinary courses.

The second suggested reform is to incorporate more project-based learning into STEM courses at Brown. Project-based learning is a popular educational model that the committee states “is becoming a priority nationally and at many of Brown’s peer institutions” (USEC 8). Project-based learning is a method of instruction that uses project questions to prompt student inquiry. The goal of project-based learning is to promote meaningful and active learning in a manner that traditional lecture classes do not. The desire for project-based learning suggests that introductory courses might focus too heavily on rote memorization and passive learning – but the STEM committee does not fully develop their reasoning for incorporating more project-based learning into introductory STEM courses and we can only infer that passive learning techniques might be contributing to student dissatisfaction with STEM courses.

The third suggested reform is to encourage “teaching science across the curriculum,” (USEC 9) a suggestion that encompasses everything from supporting the development of student writing in the sciences to emphasizing courses that deal with interactions between science and society. The committee does not properly distinguish between their recommendation for courses that emphasize the interactions between
science and society and the previous recommendation for more multidisciplinary science courses – suggesting that what they actually understood by the idea of multidisciplinary science courses were more integrated science courses. As previously mentioned, the report cites that 51% of surveyed students demonstrated interest in “interdisciplinary science-humanities courses” (USEC 9), suggesting that students would like to be learning science in a broader context. While teaching science across the curriculum might help to break down the perception that STEM programs are highly inaccessible to students not specializing in STEM fields, the STEM committee did not develop the idea of “teaching science across the curriculum” (USEC 9) in the rest of their report. The committee explains: “given the short timeframe of this committee’s work, we were encouraged not to make “science across the curriculum” a primary focus of our work” (USEC 9). Instead, the committee left this third issue to be further developed by the then newly-formed Task Force for Undergraduate Education.

Although the committee investigated curricular reform via the three afore-mentioned categories, they abandoned these subcategories when making recommendations for change. The report outlines two major recommendations for curricular reform (USEC 9-10):

1) We recommend that the introductory courses be modified to enhance multidisciplinary learning, both among STEM fields and across the Brown curriculum, and to increase the use of methods that emphasize active, hands-on learning, such as project-based instruction.

2) We recommend that the University create a pool of resources to support curricular innovation.
The first recommendation for curricular improvement – the enhancement of multidisciplinary learning and the incorporation of “methods that emphasize active, hands-on learning, such as project-based instruction” (USEC 9) is further subdivided as the STEM report suggests four different ways to realize such a goal (USEC 9-10), see Table 1.1.

<table>
<thead>
<tr>
<th>Table 1.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Add faculty-taught sections from other disciplines to an existing introductory course…These sections would show the relevance of fundamental concepts from discipline to key questions in another, foster a deeper understanding of course material, and create a more personalized and supportive environment.</td>
</tr>
<tr>
<td>b) Revise an existing introductory or second-level course to incorporate research into student experience. Examples might include courses in which students carry out collaborative investigations into specific, course-related questions under the guidance of course instructors and other faculty in the department or program.</td>
</tr>
<tr>
<td>c) Establish new multidisciplinary courses. Such courses should involve faculty from two or more disciplines, and should seek to investigate and explore fundamental concepts and scientific modes of thinking in ways that unite traditionally separate disciplines. Such courses should be open to freshmen and sophomores, and should provide well-defined entry into existing concentrations and programs of study.</td>
</tr>
<tr>
<td>d) Expand the offering of freshman seminar courses in science and mathematics that allow entering students direct experience with smaller classes led by regular faculty…Such courses have already been established in several fields, but this initiative would encourage departments and programs to offer more of them.</td>
</tr>
</tbody>
</table>

The committee notes that “significant curriculum revision or course development of a large introductory course requires a time commitment beyond the effort that every faculty member expends in improving and revising their courses as part of their regular
teaching responsibilities” (USEC 10). In recognition of the energy and resources needed to implement the proposed reforms, the STEM committee supports their first suggestion of curricular reform with the recommendation that “the University create a pool of resources to support curricular innovation” (USEC 10). Table 1.2 summarizes the 5 ways in which this projected resource pool would support curricular renewal (USEC 10-11).

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>Funds to free up faculty time during the academic year and the summer to develop and teach such courses…We emphasize that these salary funds would not represent permanent additions to departmental rosters…While the allocation of funds would be temporary, the pool itself would be permanent.</td>
</tr>
<tr>
<td>b)</td>
<td>New Graduate Teaching Assistant appointments to support such courses. Skilled help from graduate students is key to developing courses with substantial lab and research-based learning components.</td>
</tr>
<tr>
<td>c)</td>
<td>New UTRA appointments for collaborative work with advanced undergraduate students to help develop and support such courses.</td>
</tr>
<tr>
<td>d)</td>
<td>Funds to support new laboratory and teaching equipment for course offerings in science and mathematics.</td>
</tr>
<tr>
<td>e)</td>
<td>Ongoing support of technical staff to support undergraduate research, particularly in labs shared by multiple faculty and departments.</td>
</tr>
</tbody>
</table>

Table 1.2

The committee’s hope for a Science Resource Center that would enable curricular innovation takes form in their projected timeline (USEC 10), presented in Table 1.3:
Elizabeth Schibuk

The next relevant section of the STEM report is the section on Student Advising and Academic Support. The committee suggests that whether or not students feel a sense of community in their STEM programs and STEM courses affects student retention in the STEM fields (USEC 17). They write that “much of what has been written about the “climate” of science departments – a key to retention – relates to community” (USEC 17). The STEM committee’s suggestions on how to improve student retention through community building and improved advising and academic success all fall under the umbrella of the Science Resource Center. Previously, the committee presented the Science Resource Center as a resource pool to enable curricular reform, and thus aimed at supporting professors. In juxtaposition to this previous description of a resource center, here the committee presents the idea of a Science Resource Center in terms of potential to

<table>
<thead>
<tr>
<th><strong>Table 1.3</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Summer 2007</strong> Discuss recommendations for curricular innovation with department chairs, with a particular focus on departments where new hires are catalyzing curricular change.</td>
</tr>
<tr>
<td><strong>2007-2008</strong> Conduct regular meetings of faculty across departments and disciplines to discuss models and strategies for achieving curricular innovation, with co-sponsorship from the Sheridan Center and the Science Resource Center; establish seed funding for the pool of resources for curricular renewal and develop a proposal-based process for allocation of these resources.</td>
</tr>
<tr>
<td><strong>2008-2009</strong> Offer the initial round of new and revised courses; continue faculty discussions of successful innovation; seek additional support for the pool of resources for curricular renewal, including foundation and donor funds; fund the first round of curricular proposals.</td>
</tr>
<tr>
<td><strong>2009-2012</strong> Regularly review “best practices” for new courses and course models as a joint effort of the Science Resource Center and the Sheridan Center; share these findings with faculty through ongoing discussions; continue to fund proposals from the pool of resources for curricular renewal.</td>
</tr>
</tbody>
</table>
support undergraduate students. The science resource center would aim to help students “find course assistance, choose concentrations, connect with departmental academic advisors and research opportunities, while also providing support for university-wide student groups, study-skills programs, a potential pre-Freshman summer program, course study groups, graduate school and career advice, etc” (USEC 18). They continue to describe their vision for the Science Resource Center as occupying a single physical space that is a “well placed, well designed, attractive center” (USEC 19). The physical layout of the Science Resource Center seems to be a priority for the STEM committee. The committee writes that “the SRC will be a well-equipped, well-appointed space that…will also communicate the energetic, interactive, collaborative nature of teaching and learning science at Brown” (USEC 24).

In the curriculum section of the STEM report, the committee described five ways in which the Science Resource Center help improve the STEM curriculum. In the Advising and Academic Support section of the STEM report, the committee outlines in greater depth all of the projected functions for the Science Resource Center. Table 1.4 lists all stated functions of the Science Resource Center, as well as an abridged description of those functions that pertain to our discussion of student retention, STEM teaching, and communities (USEC 20-24):
a) Learning, teaching, discovering:
   i. The SRC will host or facilitate study groups of three basic types:
      Faculty- or tutor-led study
      Staff-facilitated
      Student-led
   ii. We will collaborate with the for-profit “Bear Paws Tutoring” company, established recently by current Brown students, which has enabled a sophisticated web-based tutor matching system that appears to be the best such system available.
   
   b) Support for student groups
   c) Science advising
   d) Outreach
   e) Curriculum Development: The SRC would host working lunches to introduce science faculty to each other, planning curriculum grants or developing new courses with the assistance or graduate and undergraduate students.
   f) Undergraduate Research
   g) Educational Communities: We anticipate the SRC being the home base to three types of intentional communities.
      i. Pre-college – Since during the summer fewer student would use the SRC, it could become a base of operations for [grant-supported summer programs in the sciences].
      ii. January at Brown: Discussions are underway about a pilot project to support first-year science students and prepare them for the second and subsequent semesters.
      iii. Learning Communities: We would like to experiment with the development of small communities of students and faculty who meet regularly based upon common courses and interests. Activities could include journal-club style talks by participants, field trips, advising, career discussions, and study groups. One model for such a program is the “Coordinated Science Program – A community-minded approach to first year science” at the University of British Columbia (www.science.ubc.ca/~csp).
   h) Data gathering: As a hub of STEM educational activity, the SRC will be in a good position to organize the collection and analysis of data related to student learning and retention. The USEC Faculty Survey revealed that only a few departments track student retention and post-Brown careers, and this type of information would be helpful in evaluating programs.

Table 1.4
Much like the recommendations for curricular reform, this section of the report on advising and academic support concludes with a prospective timeline for implementing a Science Resource Center (USEC 24):

| **Summer 2007** | Establish the Science Resource Center as soon as space is allocated; hire an administrative assistance and two graduate students to help staff the center. |
| **2007-2008** | Promote the adoption of course study groups, using the SI model where possible; enhance support for student groups; co-sponsor curriculum and pedagogy discussions with the Sheridan Center; develop advising “outpost”; initiate database of research opportunities; support NSF GK-12 and other outreach programs. |
| **2008-2012** | Continue to evaluate and expand programs, such as a Pre-Freshman summer experience, seeking foundation and donor support. |

As the STEM committee concludes their discussion on academic advising and student support, they emphasize that the development of a Science Resource Center is their top priority for improving undergraduate STEM education at Brown. Their ambitious timeline for establishing a Science Resource Center as soon as possible following the release of their report demonstrates their commitment to this idea of a Science Resource Center.

The final section of the STEM report transitions from a discussion of concrete recommendations for change to a forward-looking discussion of how the University will continue to engage the critical questions of undergraduate STEM education in the coming years. The STEM committee signs-off, in part, by pointing out that “the findings outlined in this report are clearly relevant to the university-wide evaluation of undergraduate learning now being conducted by the Task Force for Undergraduate Education” (USEC 30). The committee suggests that the Task Force consider those
questions put forth in the STEM report that “transcend disciplinary lines” (USEC 30) and pertain broadly to issues of undergraduate education.

*The Task Force on Undergraduate Education*

Since the STEM committee released their report in June 2007, the Task Force on Undergraduate Education has released to the Brown community a draft of their report that, in part, reflects back on the STEM committee’s work and affirms the need for undergraduate STEM education reform at Brown University. Here we give a brief overview of the Task Force on Undergraduate Education, and present those findings and recommendations that pertain to our investigation of undergraduate STEM education reform.

The Dean of the College and the Provost convened the Task Force on Undergraduate Education in March 2007. Their task was to “review the current state of the College and make recommendations for the future” (Brown University: Task Force on Undergraduate Education 31). The Task Force and the STEM committee had similar charges in so much as both committees were asked to review some aspect of education at Brown and to make recommendations for change. The catalysts for the two reports, however, differed slightly. The STEM committee was responsible for addressing specific concerns regarding the state of undergraduate STEM education at Brown University. The Task Force’s mission, in contrast, was directed less toward solving a specific problem and more toward preparing the University’s re-accreditation report for the New
Much like the STEM committee, the Task Force consisted of a combination of students, faculty, and administrators. Specifically, the Task Force on Undergraduate Education was a committee of four undergraduate students, seven senior faculty members, and three deans (Brown University: Task Force on Undergraduate Education). The individuals serving on the Task Force for Undergraduate Education came from a wide variety of disciplines spanning the sciences and the humanities. One member of the Task Force on Undergraduate Education also served on the STEM committee.

The Task Force tackled their questions about undergraduate education from “four broad vantage points: liberal education in general, education in the concentrations, the role of advising, and the assessment of teaching and learning” (Brown University: Task Force on Undergraduate Education 1). The Task Force investigated these issues by conducting informal interviews and conversations with various members of the Brown community between April and December of 2007, which ultimately led to the recent release of a public draft of their report.

There are some fundamental differences between the work of the STEM committee and the Task Force. The STEM committee was a faculty committee, with an associated student steering committee, while the Task Force was a single committee that combined students, faculty and administration. Furthermore, while the STEM report focuses on specific plans for developing a science resource center, the Task Force report reminds us that “a truly vibrant college experience… requires more than just resources. It demands serious critical reflection and commitment on the part of both teachers and
Elizabeth Schibuk

learners” (Brown University: Task Force on Undergraduate Education 3). Accordingly, the Task Force report stresses “the importance of engaging faculty and students in regular self-examination of their work” (Brown University: Task Force on Undergraduate Education 3).

The Task Force report is organized according to the following three categories: liberal education, advising, and teaching and learning. The chapters on liberal education and on advising are only peripherally related to successful undergraduate STEM education at Brown. In Chapter IV: Teaching and Learning, however, the Task Force specifically addresses the issues of student retention and poorly reviewed introductory STEM courses.

The chapter on teaching and learning affirms that a “special kind of relationship can begin as students and teachers exchange ideas and learn new ways of thinking about each other and the world” (Brown University: Task Force on Undergraduate Education 17) and that this relationship is critical to the undergraduate experience at Brown. They remind readers that Brown is a “university-college [where] professors are scholars who are expected not only to excel in their disciplines but also to participate regularly in the life of the College” (Brown University: Task Force on Undergraduate Education 17). According to the Task Force report, the most straight-forward way for faculty to build critical relationships with undergraduates is through effective teaching.

While the Task Force report emphasizes that effective teaching should be a minimum expectation in all courses in all fields, it highlights the extra care required when introducing students to new fields of study, particularly STEM fields that are often perceived as in-accessible to non-specialists (Brown University: Task Force on
Undergraduate Education 17). Directly referencing the STEM report, the Task Force report reminds us that science disciplines “retain fewer of the students who start out in the concentrations than do humanities and social science disciplines,” (Brown University: Task Force on Undergraduate Education 17). This disproportionate attrition rate stresses the need for an investigation into the nature and efficacy of undergraduate STEM education at Brown. Further echoing the STEM report, the Task Force admits that some introductory STEM courses “fail to engage students or to sustain their interests in the field” (Brown University: Task Force on Undergraduate Education Students 19). The committee reports that students are asking for better teaching in large introductory courses and that this concern will be addressed in the STEM disciplines by reworking STEM curricula.

In addition to addressing the issue of undergraduate STEM courses through curriculum reform, the Task Force raises the concern that “new and junior faculty members, whose reappointment, promotion, and tenure hinge in part on successful teaching, also need special support to function effectively in Brown’s open learning environment” (Brown University: Task Force on Undergraduate Education 19). While both the STEM report and the Task Force report present student frustrations with the quality of teaching in large introductory STEM courses, the Task Force addresses the issue more directly that the STEM committee did. They state their belief that “all faculty – including senior faculty – would benefit from a more systematic approach to improving pedagogy” (Brown University: Task Force on Undergraduate Education 19). The Task Force recommends establishing a faculty mentorship program where junior faculty are paired with a senior faculty mentor of their choice. The program would be designed to
enhance dialogue about pedagogy and improve the quality of undergraduate education, They elaborate that “this mentoring relationship should be framed as a collaborative and mutually beneficial one, in which both junior and senior faculty members have the opportunity to enhance their teaching, by observing another’s pedagogy” (Brown University: Task Force on Undergraduate Education 19).

In addition to their discussion on the quality of pedagogy at Brown, the Task Force engages a discussion on accountability for teaching and learning. Who is responsible for ensuring high quality teaching practices? Individual professors? Departments? Administrators? The Task Force hones in on departments to take responsibility for the ensuring high quality pedagogy in the courses they offer. They write that “given Brown’s institutional commitment to undergraduate education, every academic department bears responsibility for foregrounding teaching as a primary duty of the faculty” (Brown University: Task Force on Undergraduate Education 19). The Task Force readily admits, however, that there are several challenges that complicate the desire to make pedagogy a high priority issue in the departments. They write (Brown University: Task Force on Undergraduate Education 19-20):

Yet it is too often the case that issues related to pedagogy take a back seat to other very real and pressing departmental concerns. Carving out a space for extended, collegial conversations about teaching and learning will be a challenge, but it is, we feel, necessary if Brown is to maintain its reputation for teaching excellence.

Despite the myriad of ongoing challenges and concerns facing departments, the Task Force report raising suggests stimulating a campus-wide awareness of these issues
with undergraduate education. They recommend that “each department develop a plan to
support, assess, and improve teaching of its faculty” (Brown University: Task Force on
Undergraduate Education 20). While the STEM report raised the issue of student
dissatisfaction with the quality of teaching, only the Task Force report makes
recommendations that clearly suggest a need to begin monitoring and assessing teaching.
The Task Force also recommends that departments encourage professors to do a better
job “articulating learning objectives for all courses and for the concentration itself”
(Brown University: Task Force on Undergraduate Education 21). The Task Force’s third
recommendation for faculty professional development is for departments to directly
engage their faculty in “peer review of classroom effectiveness” (Brown University: Task
Force on Undergraduate Education 20). They expand on this idea of peer reviewing
teaching by encouraging dialogue that breaks disciplinary lines. The report speculates
that in conjunction with peer review of teaching, “best practices could be shared among
the departments through workshops and conversations sponsored by the Sheridan Center
and other units on campus” (Brown University: Task Force on Undergraduate Education
20). The final recommendation is that no matter what initiatives departments take to
enhance accountability for effective teaching, they remain transparent in how they
operate and that “faculty should know how teaching is assessed in the department, and
guidelines for promotion and tenure should clearly articulate how teaching is weighed in
such decisions” (Brown University: Task Force on Undergraduate Education 20).

Building upon the idea that faculty assessment and professional development need
to be open endeavors, the final discussions on teaching and learning addresses the need
for more rigorous and standardized faculty assessment tools. The report tells us that (Brown University: Task Force on Undergraduate Education 22):

Anecdotal evidence suggests that many students do not believe that the evaluations are actually used by departments in faculty evaluation; it is therefore not surprising that at least some students do not even take the evaluation process seriously.

The report also reviews some of the problems that the College Curriculum Council (CCC) found in their 2006 review of course evaluation methods. The Task Force reports that the CCC found that departments were using course evaluations that lacked “consistency in format – and, to some extent, content” (Brown University: Task Force on Undergraduate Education 22). Inconsistent course evaluation hinders discussion of teaching efficacy and curricular improvement, but is also more immediately and tangibly relevant to one of Task Force’s core missions – reaccreditation. Here it is important to remember that the Task Force was convened as part of the reaccreditation process with the New England Association of Schools and Colleges, and that improving course evaluation methods would “enable the kind of reporting required by Brown’s accrediting agency” (Brown University: Task Force on Undergraduate Education 22). The Task Force suggests “a centralized, on-line course evaluation system,” (Brown University: Task Force on Undergraduate Education 22) something already in place at many of Brown’s peer institutions, as a potential avenue for revitalizing the course evaluation process.

The Task Force concludes by recalling the ethic that first inspired the New Curriculum forty years ago. “Brown’s concept of education is “open” because we
actually believe that the full extent of the college experience – what we call the curriculum – belongs to everyone, to students and to faculty” (Brown University: Task Force on Undergraduate Education 26). The Task Force suggests that, while this report brings closure to their formal charge as a committee, the work itself is not yet finished. With the publication of their draft, they state that “it is time to open our conversations to a wider audience…in the hope that the ideas it contains will be further refined in the weeks and months to come” (Brown University: Task Force on Undergraduate Education 26). And the Task Force did, within five days of releasing the draft report to the Brown community, hold an open forum to discuss the contents of the Task Force report.

The forum began with a brief introduction to the Task Force on Undergraduate Education. Dean Bergeron, (Dean of the College, member of the Task Force on Undergraduate Education, and forum mediator) began by introducing each member of the Task Force. She reminded the audience that there were two central impetuses for convening the Task Force – The Plan for Academic Enrichment, and the upcoming New England Association of Schools and Colleges reaccreditation. Dean Bergeron expanded upon the accreditation issue and explained that Brown’s accrediting agency requires that the university conduct an extensive self-study in preparation for reaccreditation, which will happen in 2009, and that Brown sought permission to focus that self-study on undergraduate education. The New England Association of Schools and Colleges granted Brown permission to focus its investigation on undergraduate education, and so began the Task Force on Undergraduate Education.

Dean Bergeron then opened the floor for discussion. The remainder of the forum was structured around a question and answer session between the Task Force panel and
the audience. On one or two occasions during the hour and a half long forum, the discussion hit upon issues previously discussed in this chapter, bringing new perspectives to our understanding of the dialogues that have been taking place with regard to undergraduate education at Brown. In a discussion regarding the quality of teaching and professor commitment to undergraduate courses, one student member of the Task Force expressed the concern that “a lot of this report is about getting faculty to do what they’re already supposed to be doing” (Task Force Forum, February 4th 2008). In response, Dean Bergeron affirmed that “education requires a level of commitment from both students and faculty,” (Task Force Forum, February 4th 2008) implying that certain faculty and certain students fail to make such a commitment. Building upon the discussion of faculty dedication to undergraduate education, several members of the audience and the committee expressed frustration that the language in the report was not forceful enough to catalyze change. One professor on the Task Force, while sympathizing with this concern, did express his opinion that students don’t quite understand “the pressures that bathe faculty life” (Task Force Forum, February 4th 2008). The rest of the conversations at the forum centered around issues of advising and student support for theses and independent studies. While the forum brought a few new ideas to the discussion of undergraduate education – ideas that tie in with previous discussions on improving undergraduate STEM education at Brown – what is most pertinent is that the forum happened and that the Task Force followed their own guidelines and opened up their discussions to the Brown community.
Undergraduate STEM education reform at Brown is an issue warranting concern, and has been a topic of interest to University committees since at least 2005. Between the Plan for Academic Enrichment, the Science Cohort committee, the Undergraduate STEM Education Committee, and the Task Force on Undergraduate Education, it is clear that the university is not only aware of the need to better understand the shortcomings of the school’s undergraduate program, but that the university is also seriously interested in engaging the issue and making room for change. Having now laid out the recent history of undergraduate STEM education reform at Brown, I hope to build on this foundation in future chapters as I analyze and evaluate the recently proposed reforms. Before analyzing the Science Cohort proposal, the STEM report and the Task Force report, I will take a chapter to investigate the history, literature, and research regarding undergraduate STEM pedagogy and education reform in order to have a better informed discussion of these documents.
Chapter 2
The History of Undergraduate Science Education Reform.

The Primary barrier to reform is not money, but will – which must be driven by a compelling vision of what works.

- Daniel F. Sullivan, Project Kaleidoscope

Introduction

Having mapped out the conversations on undergraduate STEM education reform at Brown University, here I look to understand the recent history of the undergraduate STEM education reform movement beyond Brown. Understanding the history of STEM education reform allows for a better analysis of the curricular innovations that collected Brown committees have proposed over the course of the last two and a half years. In this chapter, we will treat two broad topics: content and process. Reform begins with an innovative idea – the content of the reform – and then change occurs through a well-informed plan for implementation – the process of the reform. I begin this chapter by looking at the history of the specific innovations that the STEM committee proposes, following which I address the history and research on the process of change in institutions dedicated to education.
Part One: Content – What are we Changing?

“I came here, and I sat in my multivariable calculus class…but for a while, when I was in my math classes, I thought, you know, I’m not officially dropped out of Evergreen yet. They haven’t started yet, I could just go back, cause they would be better than any of the multivariable classes here.” A friend of mine, reflecting on her experiences transferring to Brown from the Evergreen State College in Olympia, Washington, expressed to me her frustrations with her math classes at Brown. She transferred to Brown between her sophomore and junior years of college when she ran out of math classes that she could take at Evergreen, but was soon frustrated with what she described as poorly taught lecture classes and unengaged students. Thinking through what she found disappointing about her math experience at Brown, she continued that: “it was mostly the pure lecture format that prevented me from talking to my fellow students about the math.” My friend’s specific struggle to enjoy learning math at Brown by no means helps us properly understand why 36% of students abandon their interest in STEM disciplines while at Brown, but her anecdote forces us to question student perceptions of STEM courses. We must ask ourselves, what is happening in the undergraduate science classroom such that bright students with a keen interest in science are challenged to enjoy engaging in their coursework.

The STEM report recommends two major reforms to address this specific problem – the problem of monotonous science classrooms. They recommend that Brown incorporate more project-based learning and multidisciplinary learning into the
undergraduate STEM experience. While each of these suggestions is made specifically for STEM education improvement at Brown, there is a rich history to some of the innovations that the STEM committee proposed. Scientists and educators have been railing about science education crises and calling for reform for decades, and here I hope to map out the broader context in which Brown’s STEM reforms are situated.

How do we best train the next generation of scientists? How do we ensure the scientific literacy of the future citizenry? These questions, which lie at the heart of STEM education reform, are decades if not centuries old. One contemporary academic in science studies writes that “pedagogy has long been a major concern of the modern scientific professions. Hundreds of millions of dollars were spent on science pedagogy and its reforms throughout the nineteenth and twentieth centuries, both in the United States and in Europe…pedagogy has hardly been taken for granted by scientists themselves” (Kaiser 1).

While questions of science pedagogy stretch as far back as science disciplines themselves, the story of the modern push to improve science education begins in the 1950’s. With the World War II came an unprecedented rate of scientific discovery and technological development in the western world (Baez, Tisher). When the War drew to a close, the United States government did not want the pace of science to slow down, and so there were growing efforts to promote scientific development in national agendas. On May 10th, 1950, the President of the United States approved the formation of the National Science Foundation, a federal agency “dedicated to the support of education and fundamental research in all scientific and engineering disciplines” (NSF). With a new
interest in scientific progress and technological development, scientists and politicians alike began to look critically at the state of science education in the United States. Most of the immediate post-war interest in STEM pedagogy focused on secondary school level science education. In explaining the effects of World War Two on science education, one author writes (Tisher 44):

In the midst of all this change [after World War Two] an awareness began to emerge: existing high school courses were not capable of meeting societal demands for greater scientific expertise. Those most critical of the grave deficiencies in existing science courses were the scientists themselves. They saw little resemblance between high school science and the current state of science.

Similarly reflecting post-war scientists’ rising interest in secondary school science education, a different author writes (Baez 70):

[Scientists] became vigorously active in reform. As they looked further into school education they found that science was still being taught in an authoritarian manner and dispensed as a set of stable facts to be memorized in rote fashion by students and handed back during examinations. They found that the excitement of discovery, so characteristic of science, was missing and that teachers were poorly prepared.

This post-war interest in secondary science education is relevant to the discussion of undergraduate STEM education as it laid the foundation for future higher education reform movements. While scientists and educators have been interested in reforming secondary school science since the conclusion of World War Two, only in the 1970s did
they take a similar interest in investigating and reforming undergraduate science education. When scientists and educators began to look critically and undergraduate STEM education, they developed similar ideological concerns to those they had voiced regarding secondary school science: science education focuses too heavily on memorization that bears little resemblance to the active inquiry and problem solving techniques that scientists use on a daily basis.

In the last two decades there have been several publications addressing the need for undergraduate science education reform. For the duration of this chapter, when I discuss the history of innovation in science education, I will address the history of those methods as they appear in the literature both on secondary school and on undergraduate science education reform. I include some of the literature on secondary school science education reform for two reasons. First off, there is a relative dearth of literature specifically addressing undergraduate science education reform and given that the issues with these two reform movements overlap in a number of ways, reviewing the literature on secondary science education reform helps to paint a more complete picture of the controversies surrounding science pedagogy and education reform at any level. Moreover, this literature on secondary science education reform is relevant because the movement to reform secondary level science education predated the analogous movement at the undergraduate level, and is thus an important precedent to this discussion on undergraduate STEM education reform.

The first recommendation for curricular innovation presented in the STEM report is the development of more multidisciplinary courses. The phrases multidisciplinary
learning and interdisciplinary learning are used interchangeably in the literature to refer to a course, initiative, etc. that incorporates two or more distinct disciplines. Other less frequently used synonyms include transdisciplinary and crossdisciplinary. See appendix 1 to compare dictionary definitions of these two terms. Here I use the STEM report terminology of multidisciplinary learning. Initiatives to incorporate multidisciplinary learning into science education began slowly. It wasn’t until the 1970’s that educators and education researchers began to discuss a multidisciplinary approach to science education. In 1972, the University of Maryland developed a then innovative secondary school level multidisciplinary chemistry course. The course was called Interdisciplinary Approaches to Chemistry (IAC). One of the early IAC newsletters describes the program: (IAC 1973 in Bybee 2008, 76).

In molding the IAC program, equal emphasis has been placed on providing the student with a sound background in those basic skills and concepts normally found in an introductory high school chemistry course as well as developing the attitude that chemistry is not a dry, unrealistic science but an exciting, relevant human activity.

The IAC program is a good prototype for the sort of isolated multidisciplinary secondary schools programs or course curricula that began to gain popularity in the 1970’s. Even at this time, however, the discussions on secondary school science education reform were not primarily focused on multidisciplinary learning.

Although secondary school science education reform been a part of mainstream discussion for longer than undergraduate science education reform, most of the discussions on multidisciplinary learning have pertained to undergraduate reform. In the
archives of the peer-reviewed The Journal of College Science Teaching, a journal that publishes between six and seven issues annually, 119 articles appear between 1996-2008 in response to a search for “interdisciplinary” as a keyword in the article (www.nsta.org). The high frequency of articles pertaining to interdisciplinary learning reflects the extent to which multidisciplinary science education has been a part of the dialogue on undergraduate science education. In contrast, the analogous journal on high school science education, The Science Teacher, also published by the National Science Teacher’s Association, published only 79 articles with a keyword of “interdisciplinary” between 1996 and 2008 (www.nsta.org).

There are two ways to explain this disequilibrium. As we have seen, the discussions on multidisciplinary learning as a worthwhile reform for secondary science education did not gain popularity until the 1970’s, just as people were beginning to include undergraduate level ATEM education in their overall critiques of contemporary STEM pedagogy. The timing of the multidisciplinary science education reform movement could explain why disproportionately more undergraduate reform efforts focus on multidisciplinary education.

Alternatively, we can explain the disequilibrium between the recommendations for secondary level or for undergraduate level multidisciplinary science education by addressing the issues that might stimulate an interest in multidisciplinary learning. Before trying to understand the root cause of an interest in multidisciplinary learning, it is helpful to try to define the term “multidisciplinary”. Finkel, a professor at The Evergreen State College in Olympia, Washington, wrote about the college’s Conference on Interdisciplinary Education. He described how the conference facilitator asked sixteen
faculty at a particular seminar to define interdisciplinary education, and found that their definitions of interdisciplinary teaching fit one of four categories (Finkel in Smith and McCann, 214-215):

1. Teaching organized around unifying themes, whose purpose is to help students make connections between separate academic disciplines.
2. Inquiry-centered teaching
3. The organization of learning communities for students
4. [Helping] students to achieve a personal integration that represented a distinct achievement.

While there were a variety of opinions on how to define interdisciplinary learning, the most common definition, and the definition that most resembles those found in other literature, is the first one: interdisciplinary education is “teaching organized around unifying themes, whose purpose is to help students make connections between separate academic disciplines.” In defining multidisciplinary learning as a pedagogical philosophy that values building bridges between disciplines, we can infer that those who propose multidisciplinary learning are dissatisfied with the disciplinary boundaries that exist in education. The boundaries between academic disciplines are most pronounced at the university level, where academic departments are the major organizing feature for education and research, which explains why the push for multidisciplinary learning has been most pronounced when speaking about undergraduate education.

Even though education reformers have written extensively on incorporating multidisciplinary learning into undergraduate science education, there is no consensus that multidisciplinary coursework is the proper direction for STEM education reform. A
formor president of Stanford University wrote that “interdisciplinary programs have always been subject to departmental criticism on the grounds that they are less “rigorous” than the source disciplines” (Kennedy in Cole, 93). Kennedy, while not necessarily embracing or denouncing multidisciplinary education, highlights the controversy between multidisciplinary learning and disciplinary fidelity. The counter argument to the claim that multidisciplinary courses are less rigorous than standard departmental courses comes from an attack on conservative notions of rigor. Advocates for multidisciplinary science education argue that rigor need not come from a push to cover more material. One advocate for multidisciplinary learning writes that educators must abandon the “coverage-of-content mentality in favor of an explicit, reflective approach that encompasses many dimensions such as nature of science, unifying concepts, and specific science content” (Moss in Kaufman, 64). Those in favor of multidisciplinary education believe that in organizing education around “unifying concepts” (Moss in Kaufman, 62) that transcend disciplinary divides, the learning process becomes more meaningful and more rigorous.

A reform movement at St. Lawrence University provides a case study for the belief that academic disciplines are obstacles to be overcome. One faculty member at St. Lawrence wrote that professors “who cross those boundaries wearing their academic degrees get punished [while] those who perform their discipline well, developing it further, but within bounds, receive rewards like publication, promotion, and tenure” (Cornwell and Stoddard in Smith and McCann, 160-161). The same faculty member wrote that interdisciplinary learning “opens up worlds of new questions, practices, and horizons” (Cornwell and Stoddard in Smith and McCann, 16). Building off this
frustration with disciplinary boundaries, St. Lawrence began a ten-year initiative, 1986-1996, to promote and develop interdisciplinary faculty and curriculum development. In 1987, they instituted the First-Year Program, which requires all freshmen to take an interdisciplinary course team-taught by faculty from three different departments. St. Lawrence marks one of the earlier initiatives to restructure aspects of the undergraduate curriculum to include more multidisciplinary experiences. Eleven years following its launch, the First-Year Program is still running at St. Lawrence University. The St. Lawrence University First-Year Program (FYP) website describes the program as such:

The First-Year Program (FYP) at St. Lawrence is one of the oldest living/learning programs for first year students in the country…Residential colleges are the heart of the FYP. In their first semester, students live in one of 19 residential colleges with all of the other students enrolled in their FYP course. This interdisciplinary, team-taught course focuses on a topic of broad interest, and is one of the four courses that first year students take in the fall. FYP courses help students develop the writing, speaking, and research skills that they will need during and after college. A student’s academic advisor is one of the faculty members in his/her college. Additionally, the residential staff and faculty work together to help build a community in which students can develop friendships and succeed academically.

The First-Year Program at St. Lawrence is not likely the ideal model for Brown’s movement to incorporate multidisciplinary learning into their STEM programs since Brown is not necessarily looking to restructure its first-year program; nevertheless, St.
Elizabeth Schibuk

Lawrence’s First-Year Program still a good example of a successful initiative to break disciplinary boundaries in undergraduate education.

Despite isolated early reforms supporting multidisciplinary learning in undergraduate settings, committees are still writing about the need for multidisciplinary learning in the majority of undergraduate institutions that do not provide such opportunities. One well circulated report that addresses undergraduate science education reform is the 2002 publication BIO2010: Transforming Undergraduate Education for Future Research Biologists. The Bio2010 report has a section dedicated to the need for more interdisciplinary learning in the context of undergraduate biology. Despite the previously outlined arguments for and against multidisciplinary learning, the Bio2010 report takes a firm stance that undergraduate curricula need more multidisciplinary elements, and the section on Interdisciplinary Learning is mostly a literature review citing countless examples of research and reports supporting the call for interdisciplinary education. The report expresses the following view on interdisciplinary education (National Research Council 2002, 13-14):

To successfully participate in the interdisciplinary research of the future, biomedical scientists must be well versed in scientific topics beyond the range of traditional biology. Beginning exposure to these topics early is one key to education biomedical researchers who deal easily with interdisciplinary research projects.

The Bio2010 report continues to be a well read and well-cited report. In response to Bio2010, The American Institute of Biological Sciences conducted a follow-up study to determine the report’s influence, and found that “24% of all respondents (n = 342),
reported that Bio2010 has influenced the way that courses are taught by themselves or by others in their department or institution” (American Institute for Biological Sciences, 4). This study indicates that STEM faculty are reading the literature on STEM pedagogy and do know about the multidisciplinary education movement, but that something other than ignorance is preventing change.

The second recommendation for curricular innovation presented in the STEM report is the suggestion to incorporate more Project-Based Learning. The phrase “project-based learning” can assume a variety of meanings, and is often used synonymously with problem-based learning, inquiry learning, or other modes of active learning. The central idea of project-based learning, inquiry learning, and problem-based learning is that learning should begin with a question rather than an answer.

The term “inquiry,” a buzzword in the world of science pedagogy, has taken on a myriad of meanings. Here I use the definition mapped out by The Networking for Leadership, Inquiry and Systemic Thinking Team (NLIST), a team founded upon a collaboration between the Council of State Science Supervisors (CSSS) and NASA. NLIST defines "Science as Inquiry" in the following manner (www.NLISTinquiryscience.com):
Inquiry is the process scientists use to build an understanding of the natural world. Students can learn about the world using inquiry. Although students rarely discover knowledge that is new to humankind, current research indicates that students engaged in inquiry build knowledge new to themselves.

Student inquiry is a multi-faceted activity that involves making observations; posing questions; examining multiple sources of information to see what is already known; planning investigations; reviewing what is already known in light of the student’s experimental evidence; using tools to gather, analyze and interpret data; proposing answers, explanations, and predictions; and communicating the results.

Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations.

As a result of participating in inquiries, learners will increase their understanding of the science subject matter investigated, gain an understanding of how scientists study the natural world, develop the ability to conduct investigations, and develop the habits of mind associated with science.

While few map out as detailed a definition of inquiry as NLIST, most advocates define the teaching of science as inquiry as a pedagogical technique that mirrors the scientific process. I use the NLIST definition of inquiry because it references inquiry as the basis of the scientific process, while allowing flexible parameters for how scientists approach the process of inquiry and how this process can be replicated in the classroom.

Returning to the post-World War II discussions of science education reform, one strong critique of secondary science education was that the way science was being taught bore little resemblance to the inquiry processes of contemporary science. Tisher explains that “science, as a human activity geared toward the search for “truth,” involves the scientist in a continuous process of questioning and of seeking answers to those questions. Consequently there is no absolute truth, only highly probable explanations” (Tisher 22). This hypothesis of there being no absolute truth is key to understanding
inquiry-based science education. Since science is a human process of asking and answering questions, and since the answers produced are not absolute facts but hypotheses, the teaching of science should model the inquiry process that characterizes the search for “highly probable explanations”. Certainly, there are some stable and fundamental theories in science that students must master if they are able to think and work within the parameters of the relevant disciplinary paradigms, but scientific paradigms for understanding nature change often enough that understanding how theories are generated and how to engage in scientific inquiry is a fundamental part of science education.

Tisher maps out a myriad of curricular innovations that followed post-war scientists’ renewed interest in STEM education. He describes the American Association for the Advancement of Science’s (AAAS) ideals for science education in the 1950’s and 1960’s, and writes that “a basic assumption in a curriculum which follows an AAAS plan is that science can best be taught as a procedure of enquiry” (Tisher 27). Baez, who also wrote on the changing attitudes toward science pedagogy in the 1950’s and 1960’s, commented that “they de-emphasized rote-learning and promoted, instead, active participation and discovery on the part of the student. They stressed the importance of asking questions to which the now time-worn title of “inquiry approach” was given” (Baez 75). Baez’s 1976 description of an inquiry-based approach to science education as “time-worn” highlights the degree to which scientists and educations have been talking about inquiry learning over the past sixty years.

As previously mentioned, discussions of curricular reform in undergraduate level science began significantly later than the similar discussions of secondary level science
education. Understanding the earlier discussions on secondary level science provides a meaningful context for our discussion of contemporary undergraduate level science, as the problems identified in undergraduate science education are the same ones that scientists identified in secondary science education in the post-war years. Moreover, the recommended solutions to these problems with undergraduate STEM education are often just an extension of the recommendations for how to improve secondary school science.

Since people in universities began to look critically at undergraduate STEM education in the late 1970s, they have been discussing the need for more inquiry learning. The archives of The Journal of College Science Teaching archives shows 44 articles between 1996-2007 (with six to seven publications per year) addressing “science as inquiry” (www.nsta.org). The high frequency of articles published in the peer-reviewed Journal of College Science Teaching reflects the extent to which reformers have been discussing inquiry-based undergraduate science education.

The National Science Foundation – the foundation that grew out of the post-World War II national interest in science – has become a strong proponent of using inquiry in undergraduate science education. A National Science Foundation report from 1998 raised concerns that “few courses in areas of science and technology offer significant opportunities for students to develop facility in oral and written expression, or to pursue broader questions relating to the nature of scientific knowledge and inquiry” (NSF 1998, 116). An earlier 1996 version of that same NSF report concludes with the demand that "all students have access to supportive, excellent undergraduate education in science, mathematics, engineering, and technology, and all students learn these subjects by direct experience with the methods and processes of inquiry” (NSF 1996). While the earlier
scientists might not have phrased their recommendations with the same authority as the more recent NSF reports, these recent demands for inquiry based science education are strikingly similar to the immediate post-war outrage that science education bore little similarity to the scientific process.

Echoing NSF reports on undergraduate science education reform, the report BIO2010: Transforming Undergraduate Education for Future Research Biologists raises the concern that “many science and mathematics courses are taught as a set of facts, rather than by explaining how the material was discovered or developed” (National Research Council 2002, 3). In the vein of incorporating more inquiry experience into the undergraduate science curriculum, the report suggest providing all students with a chance to get involved in laboratory research. The authors state that “the main idea of inquiry is for students to learn in the same way that scientists learn through research” (National Research Council 2002, 16), and the most natural way to foster this sort of inquiry is through undergraduate research experience and laboratory courses.

While inquiry and problem-based (or project-based) learning have not become the mainstream method of instruction in the majority of research university STEM programs, there are a number of universities that have successfully worked these pedagogical techniques into their curricula. The University of Delaware, for example, has incorporated problem-based learning into all of their basic science courses (The Boyer Committee on Education Undergraduates in the Research University). In a Fall 2003 syllabus for a general chemistry course (CHEM – 103H) at the University of Delaware, the professor describes her course as such (Groh):

The traditional lecture approach to teaching is an excellent way to transfer
information from one notebook to another; unfortunately, it's not necessarily an excellent way to develop a real understanding of chemistry. You don't learn how to ride a bike or speak French by listening to someone explain how to do it - you've got to try it yourself. To learn any subject well, including chemistry, you have to become actively involved in the learning process. The format of this course is designed to encourage that involvement by combining a problem-based, group-centered introduction to concepts with whole class discussions and lectures.

At a later point in the syllabus, the professor clearly explains to her students the rational behind her alternative approach to general chemistry education (Groh):

In problem-based learning, real or potential problems and situations are used to introduce various ideas or topics and to serve as focal points for learning new material. You may find this a bit unusual, if you're accustomed to only working on problems after all the pertinent material has already been thoroughly discussed in class. The rationale here is to have the problem provide a context and reason for learning the material: you're not expected to be able to come up with a solution instantly - in fact, if you can, then I've written a poor problem! The problems are meant to encourage a discussion within small groups of students about what knowledge or insights each person can bring to the situation, what information you collectively still lack, and where to find that information.

Dr. Groh’s general chemistry class is an example of where an introductory level science class at a research university has broken free of the traditional lecture format and
successfully incorporates the principles of problem-based learning into a rigorous chemistry course. To see a sample problem from Dr. Susan Groh’s problem-based learning general chemistry course, and a selection of other sample problem-based learning questions from the University of Delaware STEM departments, please refer to appendix 2.

Much like the previous introduction to multidisciplinary learning, this brief introduction to inquiry-based science education is far from an exhaustive history of the subject. Rather than provide a complete history of inquiry-learning, this overview highlights the repetitive nature of these discussions on inquiry-based science education.

*Part two: Process – How does Change Happen?*

Since scientists began to develop an interest in science pedagogy in the 1950’s, they have been writing about science education reform with an unwavering sense of emergency. Sheila Tobias’ 1990 book on undergraduate science education reform indicates that some three hundred reports addressing the problems with science and mathematics education were published between 1983 and 1990, which works out to a rate of about one major report per week for seven years (Tobias). The author elaborates that “what is immediately striking about this “culture of reform” is how ardent and energetic reformers seem to be in inventing the new; yet how difficult reform is to implement, propagate, and sustain. They shake, but nothing moves” (Tobias 15-16). If the recommendations for undergraduate STEM education at Brown are recognized as worthwhile improvements, and scientists and education reformers have been discussing
similar reforms for nearly six decades, why are we still struggling with sub-par undergraduate science programs?

A number of meta-analytic studies on science education reform suggest that what is impeding successful change is that reformers and educators hold a good idea as sufficient for effective change, without proper consideration for the intricacies of the change process. In a book about the process of reform in secondary school settings, the authors comment on the post-hoc analyses of early efforts to reform secondary education in the post-war decades (Hall and Hord 7):

Evaluators were right to report “no significant differences” related to innovations, but were incorrect to conclude that the innovations were at fault; rather, we believe that the process of implementing these innovations had gone awry or was not fully addressed. Consequently, the innovations were frequently not fully implemented and, therefore, not fully tested.

The early meta-analytic studies of education reform revealed that very little had changed with the state of science education in the United States despite perpetual energized pushes for innovation. While some educators and scientists began to take issue with unsuccessful reform efforts, others kept demanding change. Hall and Hord, however, belonged a new wave of education reform researchers seeking to understand why the suggested innovations were not taking hold.

One common idea keeps surfacing in the literature evaluating education reform: a good idea is not sufficient for successful change. Recommendations for reform must consider the specific context of the institution for which they are intended if they are to effectively take hold in an institution. In a look at why well thought-out and strongly
supported ideas for undergraduate science education improvement are unsuccessful, one author notes the following (Tobias 16):

> Another aspect of the science reform culture is that recommended changes are often out of context both in terms of institutional limitations and the needs and abilities of the students and faculty they are supposed to serve. This indifference to context may also reflect the habits of doing science, for it appears to rest on an unexamined belief that, once articulated, the “right way” will be self-evident, teacher-proof, and appropriate for a wide variety of institutions.

Other researchers and reformers are beginning to share Tobias’ opinion that context must be considered in conjunction with the content of recommendations for reform. Again speaking to the need to provide a context for reform, one author writes that “one must deal with what happens in teaching and learning as part of an interlocking process involving the participation of multiple actors bound together” (Maehr 126).

The cycle of fruitless attempts at science education reform has prompted an interest in better understanding the process of institutional change. One common theme that surfaces in this growing literature on education reform is the demarcation between innovation and change. Although some writers continue to ignore the distinctions between an innovative idea and an action plan for change, many writers implicitly consider innovation to be the parent of change (Tobias 18). If innovation is the precursor to change, then innovation and change are both necessary steps in the change process: first comes the idea, and then come strategies to realize the idea. Despite the notion that
innovation and change are necessary compliments, the two often come into conflict (Tobias 18):

In some instances (and science education reform is one of these) innovation and change are in competition for reformers’ energies and dollars. In any such competition, innovation wins because innovation is more interesting than change – more experimental, less troublesome, and less political. But what if innovations have little effect on things as they are? No one wants to believe this, yet it may be true.

Tobias suggests that innovation and change are related processes that operate in conjunction with one another, but that limited time and limited attention leads reformers, educators, and administrators to focus on the far more seductive idea of curricular innovation at the expense of a proper consideration for the change process. One review of a study on institutional change in education settings states that “adoption of a project did not ensure successful implementation…what a project was mattered less than how it was carried out” (McLaughlin 12). Even though curricular innovation is a provocative subject, an innovative idea does not stand alone as a sufficient catalyst for successful change.

Education reform suffers not only from disagreements on the distinction between innovation and change, and the relative importance of each, but from disagreements on the very meaning of innovation. The Merriam-Webster dictionary defines innovation as “the introduction of something new” or “a new idea, method, or device” (Merriam-Webster). The Oxford English Dictionary similarly defines innovation as “a change made in the nature or fashion of anything; something newly introduced; a novel practice,
method, etc” (Oxford English Dictionary). These definitions are congruent with one another as well as with colloquial uses of the term, and yet the element of novelty common to the above definitions is not so widely implied in discussions of innovation in science education. In Change in Schools, the authors write early on that “the term innovation is used…to represent the program or process being implemented. It does not necessarily represent something major, new, large, or dramatically different” (Hall and Hord 9). While Change in Schools sets the parameters for their analysis by writing that an innovation does not require an element of novelty, others continue to write about innovation in a way that implies novelty. The book Innovation in Science Education opens with the statement that “to innovate means to make changes or to introduce something new” (Baez 1). Unlike Hall’s definition of innovation, Baez does require an element of novelty as part of his understanding of the term innovation. These authors present but two of several understandings of innovation, but juxtaposing these two definitions of “innovation” exemplifies the way in which writers are discussing education reform with contradictory understandings of key vocabulary.

In this paper, I use the term “innovation” in a way that mirrors Baez: with an understanding that innovation implies novelty. Baez’s parameters for innovation, “to make change or to introduce something new,” reflect the dictionary definitions of innovation, both of which make reference to novelty. Building off Baez, Merriam-Webster, and the Oxford English Dictionary, within the context of this discussion on undergraduate science education reform, I define innovation as a new idea, method, or element woven into current education practices.
Even though Hall’s definition of innovation is irreconcilable with the one I use in this paper, his book is critical to this discussion as he writes extensively on the conflation of innovation and change. Hall expresses concern that “when an idea is introduced, it seems so obvious and makes so much sense that it is difficult to imagine there was a time when the idea was not a part of common knowledge” (Hall and Hord 42). New ideas, innovations, can seem so glaringly brilliant that they blind reformers from the need to nurture the innovation through various challenging stages of implementation.

Highlighting this imbalance between interest in innovation and in change mechanisms highlights the need for greater discussions on change that directly complement discussions on innovation. Tobias begins to introduce the sorts of questions that can catalyze such discussions (Tobias 19-20):

The process of transforming innovation into change…is essentially political. And it is necessary to ask political questions: Who wants change? Who is going to be made to feel insecure? Who profits from the status quo? How can the necessary players be gathered to counter institutional inertia? And, most important, how can the innovation be structured, even if it means it is less “perfect,” so that it serves other needs of the organization? Many educational reformers, scientists in particular, fail to understand how political this process is.

Tobias lists just a few of the questions worth considering when discussing the process of systemic change beyond innovative ideas. The literature on institutional change, both general and specific to education, is expansive. This paper skims the surface of this
literature on institutional change, only enough to introduce the variety of questions and attitudes worth considering when addressing education reform.

The past sixty years of writing on science education reform suggests that there has been and continues to be a constant perception of crisis in science education, leading to repeat calls for innovative reforms that would address these “contemporary” problems. For decades now there have been generations of reformer rediscovering the same persistent problems with education, but continually misrepresenting them as either new issues or as issues that have recently become far more severe. Gerald Bracey, in a recent response to a Bob Herbert editorial in the New York Times, wrote the following (Bracey):

You will recall, I’m certain, that in Groundhog Day, the movie, the same day keeps happening over and over and only Bill Murray notices. It’s like that with education reformers and, alas, the education media. As you say, some of us are pretty dopey, “but those who cannot remember the past are condemned to repeat it” (Santayana, and those who misquote Santayana are condemned to paraphrase him).

Can we break this cycle of uninformed and hasty crisis management in education reform? In the last few decades, very much in reaction to successive poorly executed innovations, individuals researching institutional change in education call for the need to take a more modest and slow-paced approach to reform. The plea for taking small steps en route to change is based on the tenet that change is a process, not an event. Halls’ book on change in secondary school science education introduces the idea of incident interventions, which he describes as the “small moment-to-moment and day-to-day
actions” (Hall and Hord 142) that work improve education systems. Hall asserts that “it is clear that these incident interventions make a significant difference in the outcome of the change process” (Hall and Hord 142). Systemic change is a long and complex process, and is most manageable when modest incident steps are the basis for implementation.

Reformers have begun to recognize the structural obstacles to successful education reform in research-universities, and many have begun to recognize the advantages of more modestly paced reform. The Bio2010 report, which has the specific goal of improving the quality of undergraduate biology education, suggests improving biology courses by incorporating modules “as a way to modify courses without completely revamping the syllabus. The committee uses the word “module” to mean a self-contained set of material on a specific topic that could be inserted into various preexisting courses” (National Research Council 2002 6). The idea to improve courses one module at a time rather than pushing for complete one-time restructuring of old courses or development of new courses reflects Hall’s premise that change is a process, not an event.

Another common theme when discussing institutional change is the idea that reform works best when the direction and energy for change come from within the community in need of reform. With specific reference to undergraduate STEM education improvement, Tobias writes: “nowhere is an outside idea – not even an outside expert – as vital in achieving high quality instruction as local initiative and control…much of what works best is internally generated and paid for” (Tobias 13). Several education researchers have begun to apply this theory that individuals within an institution must be
the ones to initiate change to the case of the modern research university. One challenge facing modern research universities is that responsibility for the quality of undergraduate education is diffuse, and so it is challenging to know where to look when the system is not meeting expectations. Despite the challenges of diffuse responsibility, researchers have focused a considerable amount of attention on what departments and universities can do to improve the quality of undergraduate education.

Despite the push for multidisciplinary programs that would begin to dismantle the barriers between disciplines, many writers continue to validate the existence of university departments and emphasize their role in structuring undergraduate programs. The Bio2010 report, which does promote multidisciplinary learning, asserts that “there are sound academic and administrative reasons for having disciplinary science departments” (National Research Counsel 2002, 102), but that disciplinary departments are not taking responsibility for ensuring the type of interconnected learning that the Bio2010 committee is advocating. A different National Research Counsel publication on improving undergraduate STEM education calls for departments to be formally responsible and accountable for time and resources to the issue of education reform. The report claims that “it is a departmental responsibility to ensure that the instructional needs of all students are met” (National Research Council 2003, 6). The report goes on to explain that not only are departments responsible for ensuring the high quality of undergraduate education, but they are responsible for contributing to a “campus-wide awareness of the premium placed on improved teaching” (National Research Council 2003, 6).
Departments are not alone in needing to take responsibility for the quality of undergraduate education. Departmental faculty in modern research university setting cannot take the time for such efforts without strong support from the university administration. The authors of the Bio2010 report write (National Research Council 2002, 104):

Administrators need to recognize the time and effort required by encouraging faculty to take advantage of campus resources (such as teaching and learning centers and computer services) and supporting them for travel to conferences, workshops, and courses where they can learn and practice new teaching approaches and share their experiences with other faculty.

One report suggests that administrators must do more than just support faculty in their efforts to improve undergraduate education. The National Research Council report on improving undergraduate STEM education suggests that administrators must clearly spell out their high expectations for faculty dedication to teaching (National Research Council 2003, 5). Regardless of the tone or methods with which administrators hone in on the issue of undergraduate education, administrators must visibly and vocally encourage and incubate faculty efforts to improve undergraduate education.

Answering the question of who should initiate and support change in undergraduate science education programs does not explain how to initiate reform. Here is where Hall’s book becomes most useful, as he is writing specifically about the process of change in an education setting. His book outlines an approach to reform called the Concerns-Based Approach. He writes (Hall and Hord 5):
In too many cases in the past, it appeared that change facilitators based their interventions (i.e. what they did) on their own needs and time lines rather than on their clients’ needs and change progress. As the first step, the concern-based perspective places utmost importance on understanding the client.

The premise of the concerns-based approach is clear from the title – change begins by properly identifying the concerns of those who will be effecting and be affected by programmatic changes. Just as individuals who are a part of the system requiring reform are in the best position to catalyze it, the proposals for reform should directly address the concerns of those who will enact and be immediately affected by change. The individuals facilitating change must understand how other stakeholders will perceive change and adjust their practices. To recall Tobias’s argument, change is political and cannot happen successfully without careful consideration of the personnel politics that come hand in hand with institutional reform.

The Concerns-Based Approach to institutional change explains how reforms should identify what specific problems need to be addressed, but does not explain how to begin problem solving once issues have been identified. Tobias’ book, *Revitalizing Undergraduate Science: Why Some Things Work and Most Don’t*, specifically addresses ways of effective problem solving when dealing with undergraduate science education reform. Her book was the result of a two-year project where she set out to find undergraduate programs that work, and to identify why they work. She defined a program that works as one with “successful recruitment of students; a high rate of retention of those crossing the introductory threshold; and student and faculty morale”
What Tobias noticed has much to do with our discussion of step-by-step reforms. She found that successful programs were rarely the result of grand innovations and programmatic renovations, but that they came from slow, incremental improvement of previous programs. She found that most “innovative” projects were improperly managed, insufficiently funded, and hastily employed, and in the long term did little to “revitalize” undergraduate science. In contrast, more modest and continuous reforms had a more pronounced and long-term effect on the success of their undergraduate science programs. Tobias found that they approached the idea of reform in a rather precise way. Rather than trying to erase problematic programs and start from scratch, these schools were identifying what was working well in their system, and doing what they could to support and propagate the programmatic elements that were achieving success. The researchers who wrote about the Concerns-Based Approach to change also wrote that the person facilitating change must learn to see opportunities rather than constraints within their programs.

The theory that reform begins by identifying success has taken a specific form in the discussion on undergraduate education reform. Reformers cannot begin to problem-solve without an understanding of what is working well and less well, and they cannot evaluate the relative success of their programs without a well-constructed evaluation mechanism. The National Research Council report on improving undergraduate STEM education observed that (National Research Council 2003, viii):

The evaluation of teaching accomplishments has been more hap-hazard and less rigorous, particularly at research universities. Some faculty are not convinced of the objectivity of techniques used for describing the
effectiveness of teaching and learning, especially at institutions at which competing demands on faculty time make it challenging to balance all of the normal faculty responsibilities and to focus on classroom and laboratory instruction.

While the myriad stakeholders hold a wide range of opinions on how rigorously undergraduate instruction should be monitored and evaluated, most of them share frustrations with current metrics and processes for evaluating the quality of undergraduate education. University departments and administrators cannot properly identify the problematic aspects of their programs or the programs uniquely successful without a trusted mechanism for evaluation.

Once reformers have identified the areas of their programs needing reform, they must ask: what needs changing? In the most simple cases of education reform, programs, curricula, or policies are changed. These are the most straightforward and concrete items to address. However, many researchers who write about systemic change in educational institutions will write about how genuine systemic change cannot occur without a change in institutional culture. One researcher writes, with respect to K-12 education, that “the problem is rooted in the core beliefs held by staff, leaders, and teachers; it lies in the perceived purposes, goals, and personal incentives that are associated with schooling” (Maehr 53). Maehr continues to explain that school cultures vary and that not only does a reformer need to consider the cultural context in which it is operating, but must also consider how that culture is going to evolve to support the new directions that the institution is looking to take. Maehr describes the following elements of school culture: groups and groupings, roles, status, management mechanisms, myths artifacts and
symbols, beliefs, values and goals (Maehr 60-62). While this list might appear more appropriate to an anthropologist than to an educational researchers, Maehr and others are calling an ethnographic look at institutional culture as part of the reform process.

Several critiques of undergraduate education reform directly reflect the theory that institutional change requires culture change as well as new programs and policies. One common argument highlighting the need for culture change comes from reformers who express concern with reforms that operate by providing more resources to faculty. They question the usefulness of increased resources when certain aspects of culture are ignored: Why will faculty be inclined to make use of new resources? One secondary school reform researcher explains his “strong belief that the problem of schools is not just (or primarily) lack of resources. It lies in how these resources are distributed and exploited” (Maehr 124). The need to consider culture change is even more pronounced in universities, where faculty have even more responsibilities to distract them from taking advantage of extra resources promoting high quality undergraduate teaching.

*Case study: State University of New York at Buffalo*

Changes at the State University of New York at Buffalo (S.U.N.Y.A.B.) in the 1960’s serve as a useful case study to illustrate the way that the concepts mentioned in this chapter can determine the success or failure of an attempt to reform a university.

The University of Buffalo was founded in 1846 exclusively as a medical school. Throughout the 19th century, the school continued to grow by adding professional schools
and graduate schools. Only in 1913 did the school begin an undergraduate program by inaugurating the College of Arts and Sciences. Even though the University of Buffalo now had a college, the university’s primary concerns were its graduate and professional programs. The College of Arts and Sciences was treated as an “unwanted stepchild,” (Levine 30) according to education reform scholar Arthur Levine.

By the late 1950’s the University of Buffalo was experiencing financial difficulty and in order to access state funding, joined the network of State Universities of New York, to become the State University of New York at Buffalo (S.U.N.Y.A.B.) in 1962. The merger with the state university system required the University of Buffalo to seriously re-look its undergraduate program. When the University of Buffalo became S.U.N.Y.A.B., they received $650 million from S.U.N.Y. toward the construction of a new campus (Levine 35). Martin Meyerson, who was President of University of Buffalo when it became S.U.N.Y.A.B., formed a committee to figure out how this new campus could best serve S.U.N.Y.A.B.’s new priority – a high quality undergraduate college (Levine 35). Meyerson appointed top university administrators to the committee with the dean of the graduate school, Robert Ketter, as the committee chair. The committee met for at least 2.5 hours a week over the course of about twelve weeks (Levine 36), before reporting back to Meyerson.

The committee’s essential recommendation was for a college system that would provide small communities and educational units within an otherwise large and impersonal state university. The Ketter committee’s report, however, sparked indignation on several fronts when presented to the university community in September 1966. Levine writes (Levine 39):
The student body president objected to the absence of students on the Ketter committee; a departmental chairman said the proposed change flew in the face of departmental excellence…and a graduate student representative said that undergraduates and graduates had dissimilar interests and needs, so that a single curriculum would be inadequate for both.

Levine also highlights that “the Ketter report might have been a potential threat to the very basic security needs of the faculty because it challenged their multiple beliefs about appropriate values and norms” (Levine 38). Not only was the report contentious among the faculty and the students, but the university administrators and faculty who served on the committee held conflicting views on what the new S.U.N.Y.A.B. campus should be. Levine writes about the committee that “the mood was rancorous, so much so that the deliberations of the committee were still sealed in the S.U.N.Y.A.B. archives 10 years later (Levine 36). Even when browsing the S.U.N.Y.A.B. web page about the university’s history, there is no mention of the struggles to create a strong undergraduate program following the University of Buffalo’s merger with the S.U.N.Y. system.

The Ketter committee’s obstacles in trying structure the new S.U.N.Y.A.B. campus exemplify the ways in which disregard for the complicated nature of the reform process can paralyze a group of intelligent university faculty and administrators with a good idea for change. Ketter’s committee suffered from an over-ambitious timeline. The mere two months that the committee had to work on their report was not enough to build solid consensus, which ultimately compromised their ability to provide a thorough and well organized proposal. Secondly, the committee was composed of important university personnel rather than by a more diverse committee of stakeholders. Had the committee
been working from a more local standpoint, they would likely have been less likely to affront so many individuals and less likely to suggest that they were imposing reform. Not only was the Ketter committee not in the hands of the individuals who would be most affected by its recommendations, but the committee did not properly engage the university community in their discussions and did not seek to understand the particular concerns of various interest groups. Lastly, the committee did not properly consider the sort of culture change that would need to take place in order for their suggested reorganization of the entire school into a college system to gain support and momentum.

Despite the procedural flaws of the Ketter committee’s work, they proposed valuable ideas and their recommendations were not made in vain. Meyerson, the S.U.N.Y.A.B. president who founded the committee, used the report to stimulate dialogue throughout the university community and to solicit feedback. Meyerson then reviewed the committee’s reforms, and proposed recommendations that were more modest versions of that which the committee had originally suggested. Meyerson earned his reputation as a reformer as the faculty senate unanimously approved his recommendations the day he made them (Levine 42). In describing Meyerson’s success, Levine writes: “Meyerson’s choice of a more practical, less far-reaching solution permitted him to be more explicit in his formulation. Because his proposals were not particularly threatening, the greater detail offered enhanced clarity not internal chaos and university criticism, as would have been the case with the Ketter committee” (Levine43).

The S.U.N.Y.A.B. case study of successful university reform is particularly useful in illustrating the abstract theories about institutional change presented in this chapter. The Ketter committee’s rushed and audacious report triggered little change while
eliciting strong criticism. Despite their oversights, when Meyerson took the principal ideas of their work and presented those ideas to the university community in a more cautious and inquisitive manner, he met tremendous success. In the end, Meyerson was able to have innovative reforms unanimously approved because he had the patience to pace his efforts and the humility to seek feedback from those who would be most affected by the University restructuring.

Conclusion

The scope of this paper does not allow for more than a cursory introduction to the history of science education reform. The narrative I give in this chapter is not enough to provide a complete understanding of the nuanced dialogues on multidisciplinary learning or inquiry-based science education, but is hopefully sufficient to reinforce that each of these topics has had a significant presence in discussions of undergraduate science education reform over the past three decades. Similarly, my introduction to theories on institutional change only briefly engages a large area of research. Acknowledging the enormity of the subject of institutional change, I do not intend this discussion to be an exhaustive literature review. This discussion on institutional change is intended to introduce the reader to the idea that if innovative reforms in science education are to have lasting effects, then reformers must consider the context of the institution in which they are operating.
Chapter 3

Evaluating Brown’s Undergraduate STEM Reform Effort

Given Brown’s institutional commitment to undergraduate education, every academic department bears responsibility for foregrounding teaching as a primary duty of the faculty. Yet it is too often the case that issues related to pedagogy take a back seat to other very real and pressing departmental concerns. Carving out a space for extended, collegial conversations about teaching and learning will be a challenge, but it is, we feel, necessary if Brown is to maintain its reputation for teaching excellence.

-Task Force on Undergraduate Education

Introduction

In the previous chapter, I reviewed the broad history of STEM education reform, hopefully providing a context for the similar discussions that have been happening at Brown. Here I use this history and theory of education reform to analyze recent efforts to improve undergraduate STEM education programs at Brown. Analogous to the previous chapter, this chapter begins with a review of the specific recommendations for improving undergraduate STEM education at Brown, followed by a review of the change processes and procedures that the relevant Brown committees have followed.
Content - Do the recommendations make sense?

Curriculum, resources, and evaluation: these are the three broad areas of reform that continue to surface in committee reports regarding STEM education reform at Brown. Each of these categories is part of a large network of actors composing the education system, but here I will treat curriculum, resources, and evaluation as distinct categories in order to better understand how the publications on STEM education at Brown reflect specific ideas commonly discussed in the STEM education literature.

Both the STEM report and the Task Force report stress curricular innovation as a method for improving undergraduate education STEM at Brown University. Both reports highlight that large, lecture-format introductory courses are in part fueling the high attrition rates from STEM programs. Both committees view curricular innovation as a means to overcome the inadequacy of current introductory level STEM courses. Viewing curricular reform as a solution to unsatisfactory STEM education appears to be a common reflex in the history of STEM education reform. Brown’s STEM faculty who have reviewed undergraduate STEM education and called for curricular changes that would “emphasize active, hands-on learning” (USEC 9), are a contemporary incarnation of the post-war scientists who expressed similar frustration with secondary level science education in the decades following World War Two. The present push to reform STEM education at Brown is the continuation of decades of work to improve the quality of science education and to find ways to attract and retain potential future scientists. This history does not belittle contemporary STEM faculty’s continued push to improve STEM education. This reform movement’s repetitive nature suggests that contemporary
recommendations for curricular reform are not fads, but are sound suggestions for addressing persistent and complex systemic problems.

Both the Science Cohort, the STEM Committee, and the Task Force on Undergraduate Education highlight the desire for more multidisciplinary STEM learning at Brown. The authors of the STEM report write that “although scholarship in the STEM disciplines frequently bridges more than one field, introductory courses typically do not” (USEC 1). Again highlighting the desire for more multidisciplinary pedagogy in undergraduate STEM programs, “the Task Force recommends that a pool of resources be created to support cross-disciplinary team-teaching” (Task Force 29). Scientists have been suggesting multidisciplinary learning as a pedagogical tool for improving STEM education. The history of modern STEM education reform presented in Chapter Two helps to situate the proposal for multidisciplinary learning in the context of a larger reform movement in which scientists and science educators have been looking to create relevant and well integrated STEM curricula. While scientists have neither concurred that multidisciplinary learning is the most appropriate direction for curricular reform nor reached consensus on the precise meaning of the very term multidisciplinary, scientists and educators alike have published many reports supporting the use of multidisciplinary STEM curricula (Bio 2010; NRC Report). While Brown faculty and administrative interest in multidisciplinary learning is an old battle in the larger crusade to improve STEM pedagogy, this reform movement garners much support in a number of university STEM communities. The number of universities that have already begun to successfully move toward multidisciplinary STEM education, the number of reports that have validated using multidisciplinary education as a form of STEM pedagogy, and the
number of years over which scientists have been lobbying for multidisciplinary learning in the sciences all support the University’s desire to move toward a more multidisciplinary model of STEM education.

The STEM committee and the Task Force on Undergraduate Education also suggest including more inquiry-based learning in undergraduate STEM programs. As reviewed in Chapter Two, the premise for including more inquiry and project-based learning in STEM disciplines is to teach STEM in a way that mirrors the processes of STEM research. When Brown faculty consider the use of inquiry in STEM classrooms, they are implicitly asking questions of the nature of science. How to best teach STEM courses depends on what are perceived as the defining features of the STEM disciplines. One such question is whether methods or facts should bare more weight in STEM education. Answers to these questions influence what forms of pedagogy are most valued and most appropriate for teaching science. The Brown University reports, which stress STEM education that better reflects the scientific process of inquiry, suggest that faculty and administrators working to improve undergraduate STEM education value the methods of science as well as the facts of science.

Introductory lecture-size science classes teach science as a body of scientifically generated facts, often at the expense of an understanding of how the discipline in question generates such knowledge. Scientists, being the individuals most familiar with scientific processes, have long had interest in moving science pedagogy in a direction that favors inquiry based learning and thus better mirrors the scientific process itself. Regardless of whether or not they are cognizant of this history, Brown STEM faculty are taking up this long-time debate as they now question the efficacy of large introductory
lecture-style science classes that appear to be deterring potential future scientists. When the STEM committee expresses the need for more courses “allowing students to integrate course material with an understanding of the process of scientific discovery” (USEC 6), they echo frustrations of post-World War Two scientists who lamented that “the excitement of discovery, so characteristic of science, was missing” (Baez 70). Today, Brown University STEM faculty and administrators are not alone in suggesting inquiry as a new direction for undergraduate STEM programs. Much like the case for multidisciplinary learning, serial reports have advocated in favor of using inquiry as a means of STEM education. STEM faculty at Brown are recommending improvements that mirror those of educational researchers. While the various committee reports circulating through the Brown community rarely reference the relevant history or educational research, this literature strongly supports the curricular reforms that STEM faculty seek.

The most concrete systemic changes that the STEM committee recommends pertain to curricular innovation, but the committee also writes about the need to develop resources to promote and support curricular innovation. They suggest “a Science Resource Center that will serve as the home base for the new science” (USEC 18). The committee’s recommendation to establish a resource center to support curricular innovation marks a distinct shift from early STEM education reformers who suggested new directions for STEM education without addressing the need to incubate and support programmatic change. While the modern STEM education reform movement began in the 1950s, the 1970’s and 1980’s marked the birth of a new generation of STEM education reformers. This second generation of reformers wrote on how their
predecessor’s commitment to STEM education reform had shown few returns. While some educators and scientists contested the value of the proposed curricular innovations, others wrote that reformers needed to pay closer attention to the process by which curricular innovations such as inquiry and multidisciplinary learning were implemented. The STEM committee’s extensive description of a science resource center to support curricular innovation exemplifies the recent tendency to look more closely at methods for supporting curricular change.

One of the proposed Science Resource Center’s mandates is “to organize the collection and analysis of data related to student learning and retention” (USEC 24). Supporting the STEM committee’s interest in further examining undergraduate STEM education at Brown, the Task Force report recommends improving methods for evaluating all aspects of undergraduate education (Task Force 30). The Task Force recommends evaluating individual courses using a centralized web-based evaluation tool, an evaluation mechanism that many of Brown’s peer institutions already use. The Task Force also encourages faculty to “consider implementing a midterm evaluation process in their courses” (Task Force 30). While this suggestion does less to address the systemic inadequacies with course and teaching evaluation at Brown, encouraging faculty to seek feedback from their students helps to promote the idea that Brown strives to be a university that values undergraduate teaching.

Research on STEM pedagogy supports the curricular reforms proposed in these two reports, and yet scientists have been advocating these curricular reforms for decades. When researchers first began to investigate why the long-proposed changes to STEM education were not easily incorporated into institutional practices and were not showing
satisfactory results, many concluded that good ideas were being poorly implemented. This discussion on improving evaluation tools as a means of supporting curricular development distinguishes the STEM report and the Task Force report from earlier initiatives for STEM education reform, where reformers were pushing for curricular innovation without reference to the process of change.

*Process – How are they going about change?*

A good idea is not sufficient for successful reform. The STEM report recommendations for curricular innovation, increased resources, and improved evaluation tools are all necessary changes. So why are STEM faculty still struggling and fighting for reform? Why haven’t schools and universities seized these recommendations as opportunities for growth and developed accordingly? If they are to have a lasting effect on institutional practices, successful reforms must consider specific institutional context as well as the complexity of systemic change. Scientists continue to struggle to see their recommendations worked into institutional practices as their recommendations have a history of overlooking the intricate nature of institutional change. Both the STEM report and the Task Force report have begun to address this issue by writing about the need for resources and evaluation tools as a method of supporting curricular innovation. Here I look more deeply into the ways in which the process of change was both considered and overlooked in the STEM committee and the Task Force’s work on undergraduate STEM education at Brown.
In Chapter Two, I defined innovation as a new idea, method, or element woven into current education practices. Both the STEM committee and the Task Force use rhetoric that propagates the notion that the proposed recommendations are novel – “innovative” – ideas to improve undergraduate STEM education. While writing about changing STEM education at Brown, neither report details the relevant history of scientists trying to incorporate multidisciplinary learning and inquiry learning into STEM education. A Brown Daily Herald reporter wrote that the proposed Science Cohort was “billed as ‘uniquely Brown’” (Geller 2/2/06). The STEM committee report alone employs the terms “innovation” and “innovative” twenty two times in the first thirty-two pages of its text. In their discussion of multidisciplinary learning, they write that “if we are to promote cross-disciplinary curricula, it is important to provide appropriate incentives for the faculty to invest the effort necessary to develop truly novel and innovative courses” (USEC 8). The Task Force report writes that their student respondents “request innovative teaching methodologies” (Task Force 18) in their introductory STEM classes. To what extent are the “innovations” described in the STEM report and the Task Force report truly innovative? The proposals for curricular innovation are well substantiated by education research and are much needed reforms, but these specific innovations lack an element of novelty. Can we describe proposals as innovative when interest groups have been lobbying for such changes for sixty years?

For authors like Sheila Tobias, who write about the processes underlying successful undergraduate STEM education reform, distinguishing innovation from change is key to effective change. Tobias’ work studying undergraduate STEM education reform leads her to believe that “in some instances (and science education
reform is one of these) innovation and change are in competition for reformers’ energies and dollars. In any such competition, innovation wins because innovation is more interesting than change – more experimental, less troublesome, and less political” (Tobias 18). The STEM committee’s suggested changes are precisely the sort of experimental, troublesome, and political changes that Tobias is describing. There is little novelty to the suggestions for more multidisciplinary learning and inquiry learning in STEM education at Brown University. There is a certain degree of experimentation and political maneuvering required en route to success, and reformers must address these issues if they are to achieve systemic change in undergraduate STEM programs. Both the STEM report and the Task Force report are heading in the right direction by proposing necessary curricular changes in conjunction with plans to support those changes. However, neither report properly distinguishes between the content of their recommendations for reform, and the need to consider those reforms in the context of a much larger process of change. The following diagram maps out some of the players acting within and upon the university and affecting the undergraduate classroom experience:
Figure 3.1
While the previous diagram is not a complete representation of all actors operating within and upon a university to influence STEM education, the image communicates the complexity of this actor network. STEM reforms at Brown have mostly focused on changing what happens in the inner-most circle, the classroom. One of the obstacles to change, however, has been the difficulty reconciling classroom, laboratory, and lecture hall realities with the concentric layers of influence surrounding this inner circle. Lasting systemic change cannot occur when only addressing that which is occurring in the innermost circle; however, working entirely from the outside-in can also alienate the individuals who participate in classroom activities on a daily basis. Reform should begin with this inner-most circle, but those seeking change must have their own concept map, similar to the one in figure 3.1, to illustrate the structure in which they are operating.

Neither the STEM report nor the Task Force report openly acknowledges the elephant in the room, the beast of institutional inertia. In my concept map in figure 3.1, I try depict the complexity of institutional change without suggesting that reform is futile.

One of the ways in which Tobias describes innovations as conflicting with systemic change is through the different timeline that each requires. Reformers at Brown and elsewhere speak about innovation as though it were an event rather than a process. In Chapter Two, I introduced Hall’s concept of incident interventions, the small step interventions that occur as part of larger reform efforts. The Bio2010 report on improving undergraduate Biology education, a report that can generalize to discussions on improving education in all STEM fields, suggests improving discreet modules “as a way to modify courses without completely revamping the syllabus” (National Research Council 2002, 6). The STEM report, however, does not map out the steps required to
move from the status quo to a state where multidisciplinary learning and inquiry learning are a regular and well-executed component of undergraduate STEM courses at Brown. Despite this oversight, the STEM report implies a discussion on the process of change when they write about the proposed Science Resource Center as a means for initiating, managing, and overseeing undergraduate STEM education improvement. Faculty should continue to methodically map out ways to manage the changes that they suggest. A Brown Daily Herald article that ran during the STEM committee’s first month reads: “it might be worth reconsidering the short timeframe set out for the committee’s work. Though it is scheduled to suggest changes in Spring 2007, we believe it might take longer to generate a thorough substantive review” (anonymous 10/31/06). Even as the committee was just beginning to assemble, this anonymous writer had the foresight to envision the issues that might stem from the committee’s hasty timeline. The STEM report projected that the Science Resource Center would be established as soon as a space was secured, hopefully during the summer of 2007. Also projected for summer 2007 was the hiring of an administrative assistant and two graduate students to help staff the center (USEC 24). Now, almost into the summer of 2008, there has been little progress in establishing the science resource center. The STEM committee’s description of a Science Resource Center is the beginning of a potentially successful mechanism for improving and supporting undergraduate STEM education at Brown University, but they need a more modest timeline to enable steady progress.

Pacing change is just one structural element of reform that affects success. Looking at the demographics of those included and excluded from discussions can speak to the likely success of a movement to reform education programs. Tobias’ work on
understanding systemic change in undergraduate STEM education led her to conclude that “local initiative and control” (Tobias 13) are crucial to successful change in undergraduate education. The issue of transparency and local control was one of the more controversial aspects of the failed Science Cohort committee. The committee operated largely in private with little community consultation. The only public traces of the committee’s existence come from faculty meeting minutes and Brown Daily Herald articles. Several Brown Daily Herald articles write about how the Science Cohort committee was chastised for not seeking more professor input on their proposal. The Science Cohort committee’s isolated work exemplifies the sort of secrecy that, according to Tobias, counteracts successful change.

In direct response to critiques of the Science Cohort committee, the STEM committee was largely a faculty and student-led initiative. The STEM committee’s most significant asset might be that they were a group of STEM faculty trying to revitalize STEM education. Education researchers have noted that education reforms often fail when implemented in a top-down fashion – when administrators hand down new curricula, courses, goals, etc. to departments and to teachers. The STEM committee, however, is operating from a strategically “local” position. The committee is working under the guise of the Plan for Academic Enrichment, and thus with University sanction, and yet they are a group of STEM faculty who know first hand the realities of what it means to teach undergraduate STEM education at Brown University.

Although there are advantages to having such a strong contingent of STEM faculty on the committee, there is a counter-argument that the committee is too exclusive and that a more diverse body would have enriched the content and impact of the
Elizabeth Schibuk

recommendations for improvement. A Brown Daily Herald article that ran the same month that the STEM committee was formed foresaw this issue (anonymous 10/31/06):

The fact that many faculty on the committee specialize almost exclusively in the sciences is a potential cause for concern. If committee members are serious about conducting an evaluation that can potentially benefit the entire Brown community, we suggest they keep all faculty and students apprised of their progress in order to elicit informed feedback that can in turn shape future discussion.

While the STEM committee made significant procedural improvements compared to the previous Science Cohort committee, they were still not operating in the open manner previously suggested. Given that a key problem with the STEM report is a lack of appreciation for the complex process of education reform, welcoming in faculty with a background in education could have helped the committee’s work. While the STEM committee is mostly composed of STEM faculty, the Task Force a more diverse body as it was not limited in scope to the issue of STEM education. Much like the STEM committee, however, the Task Force would have benefited from the input of someone with an academic background in education.

Both the STEM committee and the Task Force on Undergraduate Education worked in conjunction with students to research and draft their reports. If the most successful education reforms are those operating under local initiative, then including students in committee work was a crucial gesture. However, the student representation on the STEM committee exhibits similar problems to the faculty committee in that the students selected come from a relatively homogeneous perspective. Seven of the eight
students serving on the student steering committee for improving STEM education were in undergraduate STEM disciplines, and the eighth was a Science and Technology Studies student. Given that the committee’s mandate was to improve undergraduate STEM education, it was important for them to work with STEM students. However, given that one of the major concerns with STEM education is the high rate of student attrition, the student steering committee would have benefited from the input of undergraduates who had left the STEM disciplines and are now humanities or social science students. Similarly, the STEM committee presents concerning data regarding the number of non-STEM students never having taken STEM classes, and so if they would like to properly address the inaccessibility of STEM classes, then working with students who were never STEM concentrators and have taken few (if any) STEM courses would be helpful.

Even though the STEM committee was not itself a diverse body, the committee consulted a wider range of faculty and students during their research. The STEM committee collected 48 e-mail surveys from science concentrators, which demonstrates the committee’s dedication to properly understanding student concerns with STEM education. However, much like the committee itself, the demographic of students surveyed ought to have been more diverse. If faculty and administrators are looking to better understand why students leave the sciences, then they would benefit from reaching out to students who have been turned off from the sciences and have moved into other disciplines rather than just working with those already in the sciences. The committee’s sample student population, current STEM concentrators, does not provide a complete picture of student opinions on undergraduate STEM education.
Beyond expanding their pool of research subjects, the STEM committee could have improved their process by interacting with the larger Brown community throughout their research. The committee could have held a discussion forum, well publicized and open to the Brown community, allowing them to hear a broader collection of opinions and experiences than their surveys could have provided. Moreover, such a forum would have helped to cultivate the “campus-wide awareness of the premium placed on improved teaching” (National Research Council 2003, 6) that educational researchers consider a key responsibility of University department.

Much like how the STEM committee improved upon the Science Cohort committee’s procedures, the Task Force on Undergraduate Education improved upon some of the STEM committee’s research methods by soliciting more feedback on their work before finalizing their recommendations. The Task Force e-mailed a draft of their report on Undergraduate Education to the Brown community. They invited the Brown community to an open forum on Undergraduate Education and the status of the Task Force report. In conjunction with the forum and with their circulating report, the Task Force set up an online survey system seeking feedback that would help them to revise their recommendations. They took measures to encourage university-wide dialogue about their proposed reforms, suggesting that they would consider the opinions and dynamics that exist within the context of Brown University. While the STEM committee would not likely have had time for such thorough interactions with the community given the timeline of their mandate, the rushed and closed-off aspects of their work remains a procedural flaw and an obstacle to the actualization of their recommendations. The STEM committee’s inability to deeply engage the myriad opinions and interests in STEM
education at Brown University indicates that the committee’s lifespan was too short for the group to have properly nurtured their recommendations through successful stages of implementation.

There is one last issue of demographic diversity worth considering when addressing STEM committee membership: that of professorial ranks. All of the faculty on the STEM committee were either tenured or tenure-track faculty. Given that the committee’s focus was undergraduate education, the committee could have benefited from the perspective of a faculty member who is not employed for any sort of research position, but hired primarily as a teacher.

Successful reform requires that the reformers belong to the community seeking change. Moreover, successful reform requires that those seeking to enact change engage a diversity of interest groups. The premise of a Concerns-Based Approach is that change is most effective when the movement for reform directly responds to the concerns of the individuals interacting within the system on a daily basis. In order for reforms to operate according to the Concerns-Based Approach, the reformers must have some mechanism in place for pinpointing the concerns of those whom they are looking to engage.

The Science Cohort committee received substantial criticism for never having investigated what concerns with undergraduate STEM education other stakeholders might hold. They appear to have operated in a secretive top-down fashion that is antithetical to the Concerns-Based Approach. The Science Cohort sought to “‘package and profile’ Brown’s existing sciences offerings to make the University appear more glamorous and competitive to committed, gifted scientists” (Rockland-Miller). One Brown Daily Herald article discussing the impetus for the Science Cohort quotes Paul
Armstrong: “I think that (this gravitation) is a good thing, but how do we make sure that we attract students who at age 14 or 15 have a passion for science that’s not going to change?” (Rockland-Miller). The Science Cohort proposal had very directed goals, but the fact that they developed their goals without consulting the larger Brown population led to significant faculty retaliation. One Brown Daily Herald reporter writes that some concerned faculty “worry that it will isolate its students from the student body as a whole” (Leher), and that more oppositional faculty “rightly disliked the notion of reserving elite benefits for a set of students” (Rockland-Miller).

The STEM committee appropriately begins their investigation by addressing student satisfaction. They are working within the framework of a Concerns-Based Approach as they begin by outlining statistics on student retention in STEM disciplines, and as they highlight the need for improvement based on continued disproportionate student attrition from STEM disciplines. Working within the parameters of a Concerns-Based Adoption model for change, the STEM committee used student surveys to determine the issues that most concerned students with regards to the current state of STEM education at Brown. The STEM committee’s general research survey asked students (USEC 49,50):

85
In response to the first of the above three questions, more than fifty percent of student respondents reported that they would be interested in taking interdisciplinary Science-Humanities courses. In response to question two, thirty-one percent of students reported that they would be more interested in taking STEM courses if professors were more dynamic, while close behind thirty percent of students reported that they would be more interested in taking STEM courses if the lab components were better integrated into the rest of the course. For question three, which the STEM committee placed in a separate portion of their survey, the largest voter cohort, thirty one percent, supported dedicating additional funds to ensuring “better teaching” (USEC 50). Only fourteen percent of
students voted in favor of using funds on multidisciplinary curricular programs. Again, only fourteen percent of students voted in favor of using funds for the projected Undergraduate Science Resource Center.

The STEM committee’s survey research demonstrates a commitment to understanding students’ concerns with STEM education before launching into discussions of reform. While the committee began by highlighting relevant student concerns with STEM education at Brown, at times their recommendations for change wandered from specific concerns that students had communicated. The report aptly considered the strong student desire for more interdisciplinary science-humanities courses, as multidisciplinary learning was the first and longest portion of the curricular innovation section of the STEM report. In this area, the committee responded directly to concerns that they had elicited from undergraduate students. The STEM report was less thorough in addressing students’ desires for more dynamic professors and well-integrated labs in STEM courses.

Even though students are more concerned with listless professors in the STEM fields than they are with any other proposed concern regarding STEM education, including multidisciplinary learning and a Science Resource Center, the STEM report praises Brown as “an environment that values undergraduate teaching” (USEC 5). Despite the STEM report’s claim that Brown has a strong commitment to undergraduate teaching, the report frequently highlights the need to improve undergraduate STEM curricula and teaching. The STEM committee writes extensively about curricular innovation, but it barely begins to tackle quality of instruction as a major issue affecting the perceived quality of undergraduate STEM courses at Brown. It is not surprising that
a faculty committee with such a short mandate would spend so little time addressing the
quality of instruction in undergraduate STEM programs. First off, the committee was
mostly made up of STEM educators, and so acknowledging and affirming student
dissatisfaction with the quality of teaching means explicitly criticizing their colleagues’,
if not their own, skills as educators. While curricular reform is still challenging, it still
less of a politically charged issue than trying to improve the quality of teaching.
Pinpointing areas of a curriculum that could be improved does not personally affront any
one individual’s skills the way that suggesting teacher professional development might.
Innovative curricula are key tools for successful teaching, but even the most intelligently
designed courses can fail in the hands of an unskilled teacher. An innovative curriculum
does not guarantee a high quality delivery of that curriculum. Teacher improvement and
curricular innovation ought to happen in conjunction with one another, but they are not
the same reform. To return to figure 3.1, curriculum and teaching are two primary,
interwoven, yet distinct elements affecting interactions and learning within the
undergraduate classroom. The movement to improve undergraduate STEM education at
Brown must directly address improving the quality of teaching in a forum distinct from the committee’s discussions on curricular innovation.

Much like the STEM report, the Task Force report highlights student concerns
with the quality of teaching in undergraduate STEM programs. In contrast to the STEM
report, the Task Force report, however, more directly addresses the need to improve
teaching quality and treats this reform as an improvement distinct from curricular
innovation. The Task Force report dedicates a section of their report to teaching and
learning, in which they stress the need for improving upon current mechanisms for
evaluating the quality of teaching. The Task Force acknowledges that even though
Brown prides itself on its commitment to undergraduate education, the University
currently “lacks a systematic feedback mechanism that would allow comprehensive study
of teaching effectiveness” (Task Force 17). Even though the Task Force highlights the
need for high quality undergraduate teaching, it acknowledges the myriad pressures put
on faculty especially the research demands that could distract from developing their
teaching skills. While the Task Force presents the obstacles that complicate the demand
for improved teaching, they do not excuse poor teaching, and they stress the following
points (Task Force 19):

Given Brown’s institutional commitment to undergraduate education, every
academic department bears responsibility for foregrounding teaching as a
primary duty of the faculty. Yet it is too often the case that issues related to
pedagogy take a back seat to other very real and pressing departmental
concerns. Carving out a space for extended, collegial conversations about
teaching and learning will be a challenge, but it is, we feel, necessary if
Brown is to maintain its reputation for teaching excellence.

The Task Force clearly recognizes the web of conflicting interests interacting in a
University and affecting undergraduate instruction (see figure 3.1). Recognizing these
obstacles is not enough; the Task Force should continue to build its specific
recommendations for how to deal with the institutional barriers to improving teaching.
The Task Force focuses mostly on teacher training for new and junior faculty and for
graduate students; consequently, they do not address the issue with the many tenured
faculty members who continue to receive poor student reviews. While the Task Force
would need to develop their recommendations for the ways in which administrators and departments could improve the quality of undergraduate teaching, it has made significant progress on the road to improving undergraduate education at Brown. The Task Force not only concede that there is a problem with undergraduate STEM teaching at Brown University, but they acknowledge the wide range of faculty pressures that complicate the issue. Even though the Task Force acknowledges the complicated nature of the problem with undergraduate education, they do not waiver in their assertion that teacher improvement should be a priority of the college. Referring back to the distinction between innovation and change, the Task Force’s willingness to discuss ways around the structural obstacles to improving undergraduate teaching marks the beginning of a reform process that considers the process of change in conjunction with innovative proposals.

Aside from improved teaching, student respondents expressed that they would be more interested in taking STEM courses if labs were well-integrated into STEM courses. Much like their treatment of the teaching question, the STEM committee appears to have only superficially considered students’ request for well-integrated labs. The report discusses the curricular “innovation” of inquiry-based learning in STEM courses as a way of improving STEM education. The fact that the committee is addressing inquiry-based learning, the sort of learning that undergraduate lab-work is supposed to foster, suggests that they are hearing that students are interested in well executed lab experiences as a part of their undergraduate experience. In the context of the STEM committee’s data, students are not expressing a desire for the institution of labs as a part of undergraduate STEM courses; they are expressing the desire for a lab experience that is better integrated into the course as a whole. Many might argue that too many STEM courses at Brown do
not have a laboratory component. For example, only three out of thirteen Neuroscience courses at Brown offer a lab component, and none of these three lab courses are introductory level courses. It might be the case that Brown undergraduates would like more of their STEM courses to lab experience – but this desire for more labs is separate from the desire for current lab sections to be better incorporated into the course. What is the purpose of developing more lab-based STEM courses when those that are already in operation are still not meeting expectations? When the STEM report addresses the issue of labs in current undergraduate STEM programs at Brown, they write (USEC 9):

A variety of models for project-based or research-based learning can be envisioned, from having seminar type courses with a research-oriented lab, modifying laboratories in large introductory courses to include open-ended and guided-inquiry-types of experiments, to opportunities for students in introductory courses to interact with research groups.

The above section of the STEM report highlights some viable suggestions for ways to improve inquiry in the undergraduate classroom, but does not respond to the specific student concern that, at present, introductory courses have laboratory components that are poorly integrated into the course. Following the premise that one factor of successful institutional change is the reformers’ ability to respond to specific concerns that they solicit from the relevant stakeholders, the STEM committee dedicates too much time to discussing “innovative” changes to promote inquiry and too little time discussing the issues with the status quo.

Expanding on the Concerns-Based Approach to institutional change, reformers need to understand not only what stakeholders are concerned with, but also what allows
for stakeholder satisfaction. This theory translates to the discussion on undergraduate education reform in that educators and reformers must understand why students are concerned with the quality of their undergraduate education, but must also understand when and why students are pleased with their undergraduate education. In understanding what is working within the present system, the reformers can develop a better model for how to change the areas of the institution’s undergraduate programs that continue to pose problems. While the STEM committee’s data indicates the ways in which students are dissatisfied with their undergraduate STEM programs, the committee presents no data to indicate where and why students are pleased with their undergraduate STEM programs. Better investigations of the mechanics of the problems with undergraduate STEM education would allow reformers to understand what is malfunctioning, but also what is functioning well, with the status quo. The following table lists just a few of the questions that would expand current understanding of retention and quality of education in undergraduate STEM education at Brown:

<table>
<thead>
<tr>
<th>What we need to know about the state of STEM education:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Who is leaving the STEM disciplines?</td>
</tr>
<tr>
<td>2. When are they leaving?</td>
</tr>
<tr>
<td>3. Which departments are losing the most students?</td>
</tr>
<tr>
<td>4. What departments are most successful in retaining students, or in attracting students who had not previously been considering the field in question?</td>
</tr>
<tr>
<td>5. What are students saying about the departments that are experiencing the worst student retention rates?</td>
</tr>
<tr>
<td>6. What are students saying about the departments that are experiencing the best student retention rates?</td>
</tr>
</tbody>
</table>

Table 3.3

Above are just a few questions that could help administration and departments to better understand the problems with undergraduate STEM education at Brown. The research
presented in the STEM report includes valuable data that highlights the need to address student attrition from undergraduate STEM programs, but the research is only a cursory review of the problems with undergraduate STEM programs at Brown. The research presented to date does not provide sufficient insight into what aspects of Brown’s current STEM programs help them to attract and retain undergraduates in the STEM fields.

Identifying what aspects of undergraduate STEM programs need improvement, and subsequently identifying models of success within existing undergraduate STEM programs, are still only preliminary stages in the overall reform process. Large institutional reforms require institutional culture change over time in order for the once innovative reforms to eventually become a standardized component of institutional practices. Even when proposed reforms are broken down into serial incident innovations, systemic change requires that the overarching goal of those incident innovations be an eventual change in some aspect of the institution’s culture. The STEM committee’s recommendations for improving undergraduate STEM education at Brown have avoided one of the common mistakes that early STEM education reformers often made: the STEM committee is not just mandating new programs, but they are looking to cultivate support for those programs by providing resources for professors and students alike through the development of a Science Resource Center. Providing resources for change and for new programs is key to sustainable change, and is a support mechanism that many past reformers overlooked.

A Science Resource Center would provide eager professors with easier access to resources for change, but improving access to resources does not fully address the issue of culture change. There already exists a resource center for Brown faculty looking to
develop their skills as teachers, and yet students continue to reference quality of teaching as their chief complaint with undergraduate STEM education at Brown. The Sheridan Center at Brown University, established in 1987, has as its mission “to improve the quality of teaching and the environment for learning at Brown University” (More). The Sheridan Center offers individual faculty consultation services, new faculty orientations, a faculty mentoring program for junior faculty, seminar lectures and forums on teaching, and teacher handbooks among other resources. If many of the resources that the proposed Science Resource Center would provide already exist through the Sheridan Center, and students continue to express dissatisfaction with the quality of teaching in introductory STEM courses, then providing more resources is not sufficient for long term change. Something within the Brown’s culture must change such that a significantly larger population of faculty, especially STEM faculty, are eager and able to take advantage of the resources that the University has made available.

Changing institutional culture and creating incentives for a widespread faculty desire to improve the quality of undergraduate STEM teaching at Brown is a monumental task that extends far beyond the creation of a resource center or the proposal for innovative curricula. Unless a revolution is on the horizon, the systemic change required for this overhaul will be slow. While the STEM committee makes several important recommendations, their recommendations are neither complete nor ready for implementation. Students have identified poor teaching in undergraduate STEM courses at Brown as a primary concern. Committees interested in addressing the STEM attrition issue will have to further investigate the issue of undergraduate STEM teaching at Brown before being able to genuinely affect the state of undergraduate STEM programs.
Chapter 4
Reworking Scholarship

“The university’s essential and irreplaceable function has always been the exploration of knowledge. This report insists that the exploration must go on through what has been considered the “teaching” function as well as the traditional “research” function. The reward structures in the modern research university need to reflect the synergy of teaching and research – and the essential reality of university life: that baccalaureate students are the university’s economic life blood and are increasingly self-aware.”

- The Boyer Commission on Educating Undergraduates in the Research University.

Introduction

Both the STEM committee and the Task Force committee report that students are dissatisfied with the quality of teaching in their STEM courses. While each committee presents several recommendations to help improve the quality of undergraduate STEM education, neither committee tries to tackle the issue of poor teaching. The Task Force describes the day-to-day pressures that challenge departments looking to dedicate time and resources to questions of pedagogy, but they insist that, despite these pressures, departments must find ways to address the issue of undergraduate STEM teaching. According to the Concerns-Based Approach to institutional change, successful reform
happens when reformers seek to understand and respond to the specific concerns of the individuals engaged in the system requiring reform. In the case of undergraduate STEM education at Brown, many of those concerns have to do with the quality of teaching in undergraduate STEM courses at Brown, especially in large lecture-style introductory courses. The Task Force references the problem that research and teaching are both faculty responsibilities, but when time is scarce, research often wins out over teaching in a competition for attention. This chapter is dedicated to better understanding this relationship between teaching and research as two responsibilities of the faculty in modern research universities.

*The beginnings of the modern research university*

Understanding the perceived conflict between teaching and research as competing faculty responsibilities begins with understanding the origins of the modern research university. In Chapter 2, I discussed the boom in scientific research that proceeded World War Two, and the national intrigue with scientific progress that followed. Following the War, scientists and politicians alike were calling for scientific research and technological development to be a national priority to ensure the progress of the United States. In writing about the climate of scientific research following World War Two, one scholar writes that “a veritable army of freshly minted Ph.D.s fanned out to campuses across the country…Academic priorities that had for years been the inspiration of the few now became the imperative of the many” (Boyer 1990, 10). As university-based
scientific research began to grow, universities had to expand. As such, the university experience that had once been the privilege of the few, became right of the masses. Boyer writes, with respect to the 1947 President’s Commission on Higher Education (Boyer 1990, 11):

In its landmark report, this panel of prominent citizens concluded that America’s colleges and universities should no longer be “merely the instrument for producing an intellectual elite.” Rather, the report stated, higher education must become “the means by which every citizen, youth, and adult, is enable and encouraged to carry his education, formal and informal, as far as his native capacities permit.”

In the years following the war, not only did the nation take a new interest in science and in science education, but the populace began to value research and higher education as critical to the country’s progress and no longer simply an elite luxury.

With a new federal interest in scientific research, research universities were not only expanding in size, they were also beginning to develop higher expectations for the volume of faculty research. While faculty were still being hired in part as university teachers, Universities began to evaluate them more and more as researchers (Boyer 1990, 11). As research expectations continued to rise and as a growing number of undergraduates were flocking university campuses nation wide, a new dilemma arose – the conflicting priorities of research and teaching. In the decades that followed, universities developed even stricter expectations for research output of their faculty. According to the Carnegie Foundation for the Advancement of Teaching, in 1969, forty-four percent of research university faculty strongly agreed that within their departments
was difficult for a person to achieve tenure if he or she did not publish – by 1989, eighty-three percent of research university faculty strongly agreed with this statement (Boyer 1990, 12). While Universities were becoming more accessible to the American population, the professoriate was becoming less accessible to the hoards of new undergraduates.

The conflicting pressures of publishing scholarly work and of teaching the ever-growing number of undergraduates persist today as a major issue facing research university faculty. Educators, administrators, and researchers alike write about how the current “publish or perish” regime that reigns in the research university causes tension within the faculty, whom we expect to be full time scholars and educators. Even though scholars have been writing about the tensions between teaching and research for several decades, universities have found little resolution to these conflicts. With each decade, comes a new sense of emergency, believing that this issue of quality undergraduate teaching is more pressing than ever and that this time-sensitive issue requires immediate attention. Despite this constant sentiment of emergency, the problem continues to worsen. The budding literature regarding faculty responsibilities in the modern research university, a body of literature that really began to take form in the 1980’s, lead one scholar to believe that “the 1990’s may well come to be remembered as the decade of the undergraduate” (Boyer 1990, xi). A different scholar writes that while research demands on faculty have been increasing for most of the twentieth century, that there is “a perception among college teachers that the pace has quickened in recent years” (Benditt 193).
There continue to be increasing opportunities for individuals to obtain an undergraduate education in the United States, and yet the problem persists that faculty have decreasing amounts of time to educate the growing number of undergraduates.

What would Boyer say now, in 2008, of his cry for the 1990’s to be the decade of the undergraduate? Through the 1990’s and into the twenty-first century, researchers and educators alike have continued to write about the conflicts between scholarship and teaching. Former president of Stanford University writes (Kennedy 59):

Responsibility to students is at the very core of the university’s mission and of he faculty’s academic duty. In recent times, however, research and innovation have been assuming larger roles in the American university. This probably represents a transitional state, and will be followed by the gradual achievement of a new balance in which the university’s primary product are people, with technologies secondary, and in which research and scholarship are more tightly interwoven with our responsibilities for educating young men and women.

Kennedy, writing in 1997, discusses how the current tensions between teaching and scholarship likely represent a time of transition for the American research university. Boyer had hoped that the 1990’s would mark the end of that transition. Despite their optimism that these conflicts were simply a period of transition en route to a new incarnation of the modern research university, one where teaching would be of primary importance, there continue to exist strong sentiments that teaching and research compete for faculty attention in today’s research universities.
Re-looking scholarship

While Kennedy, much like Boyer, is arguing for faculty to pay closer attention to undergraduates and for universities to demand less of their faculty in terms of research output, he also hints at a new understanding of faculty responsibilities, whereby faculty no longer have reason to perceive a conflict between teaching and research to be in conflict. He writes about an ideal where research and scholarship do not detract from teaching, but where they are “interwoven with our responsibilities for educating young men and women” (Kennedy 59). Kennedy writes about scholarship as though it is defined by research output - a majority perception of scholarship. While Boyer contests this majority view of scholarship, he concedes that “according to the dominant view, to be a scholar is to be a researcher – and publication is the primary yardstick by which scholarly activity is measured” (Boyer 1990, 2).

Boyer and Kennedy are not alone in writing on how university cultures view scholarship, according to research output. Research universities are rarely reviewed according to undergraduate teaching quality – they are reviewed according to research productivity (The Boyer Commission on Educating Undergraduates in the Research University, 7). When research productivity is the primary metric for evaluating research universities, it naturally follows that this pressure to produce research then trickles to departments and to faculty. The Boyer Commission on Educating Undergraduates in the Research University describes the problem as such:
The primacy of research within the espoused missions of American universities is attested over and over within the academic world. The standing of a university is measured by the research productivity of its faculty; the place of a department within the university is determined by whether its members garner more or fewer research dollars and publish more or less noteworthy research than other departments; the stature of the individual within the department is judged by the quantity and quality of the scholarship produced.

As the Commission itself suggests, ample groups have attested to way that the strong emphasis research universities place on faculty research can handicap other faculty duties such as teaching. In the National Research Council’s 2003 report on evaluating and improving undergraduate STEM education, the authors write: “Both within and outside higher education, the perception (and too often the reality) is that at many colleges and universities, research productivity is valued more than teaching effectiveness” (National Research Council 2003, 41). The report highlights that universities provide distinguished researchers with “endowed positions; additional research support; laboratory space; higher salaries; and few or no other responsibilities” (National Research Council 2003, 41). Meanwhile, less productive researchers “may lose institutional support, are given diminished space in which to work, are assigned fewer student assistants, or are denied tenure or promotion” (National Research Council 2003, 41). This system of rewarding or penalizing faculty based on the volume of their research output supports the perception that a faculty’s primary scholarly duty is research.
Not only is teaching is rarely painted as part of faculty’s scholarly duties, it is often portrayed as a chore. It is common in research university discourse to speak about a professor’s teaching “load,” implying a certain burden along with this responsibility. Unlike the institutional structures in place for evaluating and rewarding strong research, universities often leave it to individual departments or to the good will of individual faculty to nurture and promote strong teaching (National Research Council 2003, 41). When faculty reward systems do not equally evaluate and reward teaching the way they evaluate and reward research, Universities implicitly reinforce the perception that research, rather than teaching, determines the quality of a professor’s scholarship. In a university culture where faculty are worked hard and short on time, teaching does become a burden and a distraction from research, and teaching falls into conflict with good scholarship. Two academics from the University of California, Berkeley, write (Jamieson and Polsby 225):

Critics and defenders alike of the American research university seem more or less agreed on at least one proposition: that the activities of teaching and research are caught in a zero sum game, in which more of one inescapably means less of the other. It is easy to see how this conclusion might be reached, given the finite resources of time, energy, and money which universities and their inhabitants much manage. And so it is frequently asserted, and conceded, that the best teaching cannot occur in the presence of a strong research program.
Jamieson and Polsby highlight the way that when research and teaching are perceived as conflicting commitments for research university faculty, the quality of undergraduate teaching suffers.

While academics seem to agree that scholarship is narrowly understood as the result of one’s research, many are calling for a new understanding of scholarship that values teaching and research on level playing fields. Boyer, begging his audience not to conflate research and scholarship, writes (Boyer 1990, 16):

Surely, scholarship means engaging in original research. But the work of the scholar also means stepping back from one’s investigation, looking for connections, building bridges between theory and practice, and communicating one’s knowledge effectively to students. Specifically, we conclude that the work of the professoriate might be thought of as having four separate, yet overlapping, functions. These are: the scholarship of discovery; the scholarship of integration; the scholarship of application; and the scholarship of teaching.

Scholars continue to write about the tension regarding scholarship at American research Universities, but Boyer’s reconfiguration of the term “scholarship” allows for an equal estimation of teaching and of research as contributing to a faculty member’s scholarship and, in turn, begins to dissolve the conflict between these two faculty responsibilities.

The National Research Council report writes: “the committee maintains that the goals and perception of excellence in research and teaching at the undergraduate level can and must be more closely aligned” (National Research Council 2003, 42). Those who seek a more comprehensive understanding of “scholarship” hope that if faculty, departments, and
universities adopt an understanding of scholarship that includes teaching and research, then faculty will have less reason to talk about teaching coming into conflict with research.

Fostering belief that teaching is a valuable a part of scholarship requires changing the culture of the research university faculty, departments, and administration. As reviewed in Chapter Two, culture change is a slow and arduous process. Culture itself is often an ambiguous term. Culture change means changing how various faculty duties are evaluated, praised, and rewarded. Redefining scholarship in the modern research university means redefining how teaching and research are each evaluated and rewarded. Within the tenure-track system as it stands today, there is little hope of instilling Boyer’s new understanding of scholarship so long as faculty have reason to believe that time spent teaching will compromise their promotion along the tenure track, their salaries, and their scholarly notoriety.

There are several obstacles to a new understanding of scholarship in American research universities. First comes the issue of teacher training. The United-States puts so much effort into grade school teacher training; why do we assume that any researcher is necessarily qualified to teach? While an increasing number of graduate programs are beginning to require some element of teacher training, teacher preparation still remains an insignificant portion of the graduate school curricula. The National Research Council writes that “it is important to recognize that most college-level faculty who currently teach in the STEM disciplines have never received formal preparation for teaching any students, let alone those who aspire to be teachers at either the pre-college or university level” (National Research Council 2003, 36).
Second is the issue of faculty reward systems. Teaching, like research, is not a stagnant profession. Teaching requires continual feedback, course evaluation and renewal, development of new courses, professional dialogue, and many other activities akin to those assumed to be part of a researcher’s daily activities. Successful teaching requires faculty to dedicate personal time to course development and course renewal, which are time intensive procedures for which the current faculty reward system provides no incentive.

_Evaluating teaching as scholarship_

A third obstacle to improving undergraduate teaching is the lack of proper mechanisms for evaluating teaching. Universities must reward good teaching if they want faculty to seriously consider teaching as part of their scholarly role. In order to reward good teaching, however, Universities must have a well developed method for evaluating teaching.

In many cases, Universities measure faculty commitment to teaching according to the number of courses or the number of students the professor is teaching (National Research Council 2003, 42). Often times universities use student questionnaires to evaluate undergraduate courses. Student evaluations are often influenced by such factors as class size, grading procedures, curricular requirements, etc. and thus they rarely weigh in on any significant evaluation of a particular course or faculty member. Universities are appropriately concerned about the validity of student evaluations as a means of
evaluating teacher performance – especially if student evaluations then become a basis for promotion and salary. The complicated nature of teacher evaluation should not, however, prevent the creation of multi-faceted teacher, course, and program evaluation mechanisms.

The National Research Council Report begins to tackle the teacher-evaluation mechanism issue in their 2003 report *Evaluating and Improving Undergraduate Teaching in Science, Technology, Engineering, and Mathematics*. The report details a variety of evaluation methodologies and applies these methodologies both to the evaluation of individual faculty and to the evaluation of specific undergraduate STEM programs. Table 4.1 summarizes the report’s suggested methods for evaluating teaching in undergraduate STEM programs (National Research Council 2003, Chapter 4):

<table>
<thead>
<tr>
<th>Teaching Evaluation Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Student and Colleague Input</td>
</tr>
<tr>
<td>a. Undergraduate students’ evaluations and progress</td>
</tr>
<tr>
<td>b. Colleague evaluations of teaching and of student progress</td>
</tr>
<tr>
<td>c. Undergraduate/Graduate teaching assistants’ evaluations</td>
</tr>
<tr>
<td>d. Undergraduate/Graduate research assistants’ evaluations</td>
</tr>
<tr>
<td>2. Department and University Records</td>
</tr>
<tr>
<td>a. Number, levels, and sections of undergraduate courses taught</td>
</tr>
<tr>
<td>b. Number of undergraduates mentored/advised</td>
</tr>
<tr>
<td>c. Number of undergraduates guided through original research</td>
</tr>
<tr>
<td>3. Teaching Portfolios</td>
</tr>
<tr>
<td>a. Documentation of revisions to courses and laboratory sections</td>
</tr>
<tr>
<td>b. Participation in efforts to improve department curricula or participation in cross-disciplinary teaching initiatives</td>
</tr>
<tr>
<td>c. Faculty self-evaluations</td>
</tr>
<tr>
<td>d. Participation in external teacher development and support programs</td>
</tr>
</tbody>
</table>

The National Research Council report goes into much greater detail explaining each of the above teacher evaluation methods. None of these evaluation methods stands
alone as an objective or complete mechanism for assessing undergraduate STEM teaching – but when enough of them are combined, they can provide a comprehensive picture of a faculty’s teaching success.

The approaches to teacher evaluation listed in table 4.1 describe ways to gather information on the quality of undergraduate teaching, but they do not specify what evaluators ought to look for. Table 4.2 summarizes the five criteria that the report suggests ought to be the benchmarks for evaluating undergraduate teaching, followed by key questions from the report that could help evaluate how well professors have addressed each criteria (National Research Council 2003, Chapter 6).
Criteria for Evaluating Individual Faculty

1. Knowledge of and Enthusiasm for Subject Matter
   a. Does the instructor exhibit an appropriate depth and breadth of knowledge?
   b. Is the instructor’s information current and relevant?
   c. Does the instructor show continued growth in the field?

2. Skill, Experience, and Creativity with a Range of Appropriate Pedagogies and Technologies
   a. Does the instructor clearly communicate the goals of the course to students?
   b. Is the instructor aware of alternative methods or teaching strategies and able to select methods of instruction that are most effective in helping students learn (pedagogical content knowledge)?
   c. To what extent does the instructor set explicit goals for student learning and persist in monitoring students’ progress toward achieving those goals?

3. Understanding of and Skill in Using Appropriate Testing Practices
   a. Is the instructor aware of a range of tools that can be used to assess student learning?
   b. Does the instructor select assessment techniques that are valid, reliable, and consistent with the goals and learning outcomes of the course?
   c. Are students involved in contributing to the development of assessment tools used?
   d. Are assignments and tests graded carefully and fairly using criteria that are communicated to students before they begin a task?
   e. Do students receive prompt and accurate feedback about their performance at regular intervals throughout the term?
   f. Do students receive constructive suggestions on how to improve their course performance?

4. Professional Interactions with Students Within and Beyond the Classroom
   a. How active has the instructor been in directing student research projects?
   b. Does the instructor take an active interest in advisees’ individual academic and career choices?
   c. How effectively does the instructor train and supervise teaching assistants assigned to his or her courses?

5. Involvement with and Contributions to One’s Profession in Enhancing Teaching and Learning
   a. During the term, has the instructor specifically elicited feedback from students, colleagues, or instructional experts (e.g. from the campus teaching and learning center) about the quality of his or her teaching?
   b. To what extent does the instructor meet his or her teaching obligations and responsibilities?
   c. Has the instructor made noteworthy contributions to the design and development of the department’s curriculum? Has the instructor been involved in efforts to improve education or teaching within the discipline or across disciplines?

Table 4.2
The report distinguishes between the quality of instruction on behalf of individual faculty within a given department, and the overall quality of that department’s undergraduate program. While Table 4.2 looked at criteria for evaluating individual teachers, Table 4.3 summarizes the report’s three criteria for evaluating the quality of undergraduate STEM programs (National Research Council 2003, Chapter 7):

Criteria for Evaluating Departmental Undergraduate Programs

1. Ability to Enhance Teaching and Learning in Classrooms and Other Venues
   a. Engaging student interest in the department’s curricular offerings
   b. Applying research on human cognition and learning
   c. Employing effective pedagogy
   d. Assessing student learning
   e. Emphasis on improving teaching and learning in introductory and lower division courses
   f. Incorporating advances in the discipline and related subject areas
   g. Providing academic advising and career planning

2. Efforts to Improve Teaching Laboratories and Other Undergraduate Research Experience
   a. Emphasizing the role and importance of teaching laboratories
   b. Encouraging students to engage in independent research

3. Interdepartmental Cooperation in Improving Undergraduate Science, Technology, Engineering, and Mathematics Education.

The tenure-track faculty reward system is at the very core of the way modern research universities operate, and so by some accounts changing the dominant understanding of scholarship means completely dismantling the current system. Even though scholars might argue that undergraduate teaching will suffer so long as the current system persists, it is important to recognize that attempting wholesale institutional change is rarely an effective method of improving undergraduates STEM programs. Research shows that modest and well-managed change is more effective than more grandiose
innovations. Unless frustration mounts and there is a veritable revolution at Brown University, the problems with the tenure-track reward system are not likely to change within the context of an undergraduate STEM education reform movement. To quote the celebrated physicist Richard Feynman (Feynman xxix):

There isn’t any solution to this problem of education other than to realize that the best teaching can only be done where there is a direct individual relationship between a student and a good teacher – a situation in which the student discusses the ideas, thinks about things, and talks about the things. It’s impossible to learn very much simply by sitting in a lecture, or even by simply doing the problems that are assigned. But in our modern times we have so many students to teach that we have to try to find some substitute for the ideal.

Feynman’s wisdom applies as well to the issue of tenure-track reward systems as it does the issue of large lecture-style science classes. Successful reformers must recognize the systemic obstacles that extend beyond the walls of their own institutions, such as the tenure-track system, and then move beyond those obstacles to find pathways to success by capitalizing on what works well. So long as the tenure-track system continues to consider research productivity above teaching, Universities will continue to support the belief that research determines scholarly success. So long as scholarly success is measured predominantly according to research activity, faculty will continue to perceive a dedication to teaching as coming into conflict with their scholarly pursuits.

While any given Brown committee is unlikely to overhaul the tenure-track system (should a committee even reach consensus that such change was necessary), it would be
possible for a committee to create more incentives for faculty to dedicate themselves to undergraduate STEM education. Before a committee can find ways to better reward those who have a record of exemplary commitment to undergraduate teaching, administrators and departments need a clearer and more transparent set of expectations for faculty commitment to teaching and to professional development as educators. Next, administrators need to develop more comprehensive tools for faculty evaluation. This chapter only skims the surface of the research regarding the evaluation of undergraduate STEM teaching. In this chapter, I frequently reference the National Research Council’s report *Evaluating and Improving Undergraduate Teaching in Science, Technology, Engineering, and Mathematics*. Here I have only barely looked at the report’s major guidelines for evaluating undergraduate STEM teaching. For more detail on criteria for evaluating undergraduate STEM teaching, and for a variety of sample evaluation instruments, please consult the report itself.
Conclusion

“There isn’t any solution to this problem of education other than to realize that the best teaching can only be done where there is a direct individual relationship between a student and a good teacher – a situation in which the student discusses the ideas, thinks about things, and talks about the things. It’s impossible to learn very much simply by sitting in a lecture, or even by simply doing the problems that are assigned. But in our modern times we have so many students to teach that we have to try to find some substitute for the ideal.”

- Richard Feynman

The technological developments of World War II catalyzed a national interest in science in the United States. In the post-war decades, science became less of an elite intellectual hobby and grew to be a high profile career opportunity for a growing number of individuals. The U.S. government was advocating for more Americans to engage in scientific research, for more funding for science, and for stronger science education programs. Science became synonymous with progress – and few questioned the need for progress. Shortly after the conclusion of World War II, President Roosevelt commissioned Vannevar Bush, Director of the Office of Scientific Research and Development, to investigate ways to continue to harness the potential of science and technology now that the war was over. In his letter to Dr. Bush, Roosevelt wrote the following (Bush):
The information, the techniques, and the research experience developed by the Office of Scientific Research and Development and by the thousands of scientists in the universities and in private industry, should be used in the days of peace ahead for the improvement of the national health, the creation of new enterprises bringing new jobs, and the betterment of the national standard of living.

Eight months following Roosevelt’s commission, Dr. Bush presented him with a report Science – The Endless Frontier. The report detailed the ways in which science held promise for the future of America, and emphasized the imperative for the U.S. government to invest in the future of scientific research and technological development.

Vannevar Bush’s report influenced President Truman after he took office from Roosevelt. Five years following Dr. Bush’s report, the U.S. federal government, under Truman, established the National Science Foundation and the National Science Board.

This post-war infatuation with scientific progress led politicians and scientists alike to take a keen interest in science education. Bush wrote in his report to President Roosevelt (Bush):

Improvement in the teaching of science is imperative; for students of latent scientific ability are particularly vulnerable to high school teaching which fails to awaken interest or to provide adequate instruction. To enlarge the group of specially qualified men and women it is necessary to increase the number who go to college. This involves improved high school instruction, provision for helping individual talented students to finish high school (primarily the responsibility of the local communities), and opportunities for
more capable, promising high school students to go to college. Anything short of this means serious waste of higher education and neglect of human resources.

Politicians like Bush were not the only ones who found that high school science education was failing to “awaken interest or to provide adequate instruction” (Bush). Scientists themselves began complaining about high school science curricula that failed to teach students in a way that fostered a genuine understanding of the process and excitement of scientific discovery (Baez).

With a budding national passion for the promise of science, scientists began to lobby for high school science programs that better mirrored the methods of modern science. Their major recommendation was to include more inquiry-learning into science education. Inquiry-learning was and remains a somewhat nebulous umbrella term for a myriad of educational models that encourage student inquiry as a cornerstone of their learning process. Problem-based learning and project-based learning are two forms of inquiry learning that educators often discuss in the context of science education reform. For decades following the war, educators and reformers alike continued to push for more inquiry-learning in high school science programs, but with little success.

The post-World War II investment in science also catalyzed the growth of scientific research in the modern university. As scientists began moving into Universities, they organized themselves according to their disciplines, and disciplinary allegiances grew. Boyer writes, “in the new climate, discipline-based departments became the foundation of faculty allegiance” (Boyer 10). Some scientists and educators began to find these disciplinary divides counterproductive in education – where sciences
were also taught according to specific disciplines with little reference to other relevant sciences or social sciences. Thus began the movement for more interdisciplinary undergraduate STEM education. Some were advocating for integrated science classes, while others were advocating for classes that would bridge the gap between the sciences and the social sciences and humanities. Even though there was no clear consensus on the meaning of interdisciplinary science education, many scientists and educators began to rally for the overarching goal of teaching science in a less isolated manner.

These early movements to reform science education mostly focused on secondary school level science. As politicians began to see science as the way of the future, they sought to make undergraduate science education accessible to a larger population of students. As such, in the decades following World War II, the population of undergraduate students studying science increased dramatically. With more students taking undergraduate science classes, an increasing number of people began turning their attention to science education at the undergraduate level as well. By the 1980’s, scientists were finding similar issues with undergraduate science education that earlier scientists had found with high school science education in the 1950’s. University faculty and administrators began raising concern that undergraduate science programs were focusing on rote memorization at the expense of fostering the critical thinking and creativity skills required in the scientific arena. In a similar vein to the high school science education reforms first presented decades prior, people in universities began discussing the value of inquiry-learning and interdisciplinary science in undergraduate programs.
Despite decades of strong support and lobbying for science education reform at both the high school and undergraduate level, reform has been remarkably slow. In the 1970s, when it first became clear that decades of reform efforts were yielding few results, some educators and reformers began to question the merits of the proposed reforms. Another cohort of reformers, however, contended that the lack of progress was more a result of poor implementation than a problem with the substance of the reforms. There grew an area of research dedicated to understanding institutional change and education reform. By the 1980s and 1990s, there were still increasing numbers of publications both on the pressing need for science education reform and on the complicated nature of change in the education system.

Research on institutional change and education reform has produced myriad theories and models trying to describe the most successful methods of change. While each author seems to have his or her own model for successful change, there are certain key ideas that surface in multiple works. Table 5.1 summarizes these key theories about systemic change in education:
Change in Education

1. Innovation vs. Managing Change
   a. Reformers should distinguish between the content and the process of the reforms they seek to implement.
   b. Good ideas can continue to fail if they are not properly implemented.
   c. Often innovative ideas are not as novel as they seem. There is value in understanding the history of a given reform movement.

2. Appropriately Paced Change
   a. Systemic change is often a long and complex procedure.
   b. Unless a revolution is brewing, slow incident innovations are often more successful than wholesale change.

3. Local Control over Change
   a. Institutional change is most successful when those initiating reform are those who would have to implement reforms.
   b. Top-down reform often catalyzes opposition.

4. A Concerns-Based Approach to Change
   a. Reformers must consider the specific concerns of all groups with a stake in the state of education.
   b. In order to focus change on the concerns of the individuals most affected by change, reformers have to consult with those individuals as part of their reform process.

5. Building Off of What Works
   a. Successful change depends on identifying ways in which an education system is already succeeding and which specific areas of the system are failing.
   b. Once the relative successes of a system have been identified, then reformers can base their recommendations for improving struggling programs/program areas based on local models of success.

6. Culture Change
   a. Changing the status quo for institutional practices and attitudes requires changing the culture of the institution. Systemic culture change rarely occurs as the result of a single new program, single policy change, etc.
   b. One mechanism for changing school culture is for administrators to change their reward systems according to what they want their staff to consider valuable.
For sixty years, educators and scientists have been talking about a crisis of sub-standard science education. It is in the context of this national science education crisis that Brown has recently begun developing plans to improve the university’s undergraduate STEM programs. The contemporary discussion of STEM education reform at Brown begins with the proposal for a Science Cohort program. The Science Cohort program was designed to attract top-notch science students to Brown by creating a special multidisciplinary science program that would admit 60 undergraduates each year. The Science Cohort committee, however, failed to see garner support for their program. A number of faculty criticized the proposal for only serving an elite group of science students rather than improving the quality of undergraduate science education for all students. Furthermore, the committee faced a considerable amount of faculty opposition for not having properly researched the specific issues with STEM education at Brown and not having consulted with the relevant stakeholders – professors and students. The Science Cohort committee’s work epitomizes what went wrong with early post-war science education reforms. The committee took a fundamentally well thought-out idea – a multidisciplinary science program that would seek to replicate the process of contemporary science – and hastily tried to inaugurate their program with little attention to the complexity and challenges of institutional reform.

Though the Science Cohort proposal received strong faculty criticism, Brown’s faculty was committed to the idea of improving undergraduate STEM education at Brown. Following the defeat of the Science Cohort proposal, the Dean of the College called together a faculty and student led committee to investigate the current state of STEM education at Brown. This committee, the STEM committee, spent seven months
interviewing students, student groups, and faculty trying to learn more about the state of
STEM education at Brown. In their research, the STEM committee found that Brown has
a 36% attrition rate from undergraduate STEM programs, which the committee
determined to be far higher than the rate at which students are leaving social science or
humanities programs and entering the sciences. They also found that the most significant
student frustration with undergraduate STEM programs at Brown was poor teaching.
When presented with a list of six opportunities to fund an initiative to improve STEM
education, more students selected “better teaching” than selected any other option
presents (USEC 42). The STEM committee’s research also identified the issue that
STEM courses are often uninteresting or inaccessible to non-concentrators. While a high
percentage of STEM students take courses in the social sciences and the humanities, very
few social science or humanities students take courses in the STEM fields (USEC 6).
When the STEM committee polled students, they found that the most number of students
said that they would be more inclined to take STEM classes if professors were more
dynamic (USEC 41).

After concluding their research, the committee published a report in which they
make recommendations for improving STEM education. The committee’s principal
recommendations were to promote inquiry-learning and multidisciplinary-learning in
Brown’s STEM curricula, and to create a science resource center to support STEM
students, STEM faculty, and STEM education improvement.

The STEM committee’s work vastly improved upon the issues raised with the
Science Cohort proposal. Unlike the Science Cohort, the STEM committee’s
recommendations seek to improve the quality of STEM education for all undergraduates
rather than a select elite. Furthermore, the STEM committee’s mission was less focused on redesigning undergraduate STEM education and more on unearthing the current issues with the state of undergraduate STEM education at Brown. Overall, the STEM committee was operating in a fashion that mirrors some of the key principles for successful institutional change: local control and a Concerns-Based Approach to change.

While the STEM committee’s work brought new insight and strong ideas into the discussion of undergraduate STEM education reform at Brown, their work lies incomplete. There are more key questions that need to be addressed before simply implementing the STEM committee’s recommendations would properly address the major issues with undergraduate STEM education at Brown. Tables 5.2a and 5.2b summarize these changes:
What Next for STEM Education at Brown?

1. Define Success
   a. The Science Cohort committee, the STEM committee, and the Task Force on Undergraduate Education all faced the challenge of trying to solve several problems at once. Given the short duration of these university committees, honing in on a smaller subset of issues would help to develop a more thorough action plan for change.
   b. In response to the STEM committee’s data on student attrition from the sciences and the dearth of non-STEM concentrators taking science courses, the most pressing issue is to make undergraduate STEM courses and programs at Brown more appealing to the majority of undergraduates.

2. Concerns-Based Approach
   a. The STEM committee investigated students’ concerns with undergraduate STEM education at Brown. The committee’s recommendations, however, do not directly engage the data they present.
   b. While the STEM committee invests in a discussion of curricular change, they do not respond to students’ chief complaint – poor teaching in introductory STEM courses. While the recommended curricular innovations could greatly improve these introductory classes, curricular change does not solve the problem of poor teaching.
   c. The STEM committee benefited from the advantages of a locally controlled initiative for change. If seeking to improve undergraduate STEM courses for all undergraduates, however, the student steering committee could have benefited from the presence of more non-STEM concentrators and former STEM concentrators and the faculty committee could have benefited from the perspective of faculty with a background in education. Future committees should bare in mind these demographic issues.

3. The Faculty Scholar
   a. Undergraduate science education and the modern research university changed significantly in the wake of WWII, when undergraduate education became less of an elite privilege and when science became a nationally prized endeavor and less of an intellectual pass time. These changes have led to larger and larger undergraduate institutions while simultaneously limiting faculty availability to invest in teaching as a scholarly pursuit.
   b. The tenure track system rewards research often at the expense of faculty commitment to students and teaching. This reward system poses significant barriers to motivating faculty to invest the time and thought to improving their undergraduate courses even if the University provides significant resources.
   c. In institution a Science Resource Center, reformers should think about ways to motivate faculty involvement in the center given the constraints of the current system.

Table 5.2a
What Next for STEM Education at Brown?

4. Evaluation Mechanisms
   a. The Task Force report highlights that Brown is a special case of a research university committed to undergraduate education. If the university prizes undergraduate education, then they must place a high premium on the quality of teaching. Doing so requires a system for monitoring undergraduate teaching in the STEM fields.
   b. Brown needs a comprehensive, multi-faceted mechanism for evaluating specific STEM professors, courses, and departmental programs.
   c. Brown must consider whether evaluations are going to be administered by individual departments or by a central university body.
   d. The university should begin to consider how it will use information collected from teaching, course, and program evaluations, and must clearly communicate those standards to departments, faculty, and students.

5. What Works
   a. The STEM committee report contains pertinent data regarding the status of undergraduate STEM education at Brown.
   b. When working toward systematic reform within a complex institution such as a research university, institutional inertia is a major obstacle to change. Successful reformers are those who can see opportunities for improvement and models for success within their institution.
   c. While the STEM committee presents the issue of student retention in undergraduate STEM programs, they provided little nuance to explain which programs are losing the most programs and why, and conversely which programs are attracting students.
   d. The university needs to organize further research into the successes and failures of different STEM programs and courses in order to identify what makes undergraduate STEM education successful at Brown. **See Appendix 3 for a sample research protocol.

6. Action Plan
   a. Brown needs a new committee to follow up on the work that the STEM committee began in 2006-2007. This committee should consist of a diverse body of undergraduates, faculty, and administrators.
   b. Much like the STEM committee, this new STEM education committee should begin with researching undergraduate STEM education at Brown, and follow-up with a series of recommendations.
   c. This new committee should have a longer mandate than either the STEM committee or the Task Force, allowing time for more substantive research and more follow-through on their recommendations.
   d. The committee should be mindful of all of the afore-mentioned recommendations for further developing the undergraduate STEM education reform movement at Brown.
In the past three years, Brown has seen successive committees try to address the issue of undergraduate STEM education reform. From the first stages of a Science Cohort proposal in 2005 to the Task Force’s first public draft proposal in early 2008, there has been great progress toward improving undergraduate STEM education. Each committee has improved upon its predecessor’s work to be able to recommend programmatic changes that more and more seek to address the specific concerns regarding STEM education at Brown, while being mindful of the larger national crisis with STEM education. Furthermore, with each new committee comes a more refined process for investigating STEM education and for suggesting changes. The work to reform undergraduate STEM education at Brown is still in its early stages. More research and problem solving must go into this reform movement, both of which will require time and patience. The progress, the ideas, and the energy of recent committees bode well for the future of undergraduate STEM education at Brown. With the right leadership and the right commitment, Brown could bare witness to exciting progress over the course of the next decade.
Appendix 1: Glossary

**Culture:** Groups and groupings, roles, status, management mechanisms, myths artifacts and symbols, beliefs, values and goals (Maehr 60-62).

**Curriculum:** a set of courses constituting an area of specialization (www.mirriam-webster.com).

**Innovation:** A new idea, method, or element woven into current education practices.

**Inquiry:** Student inquiry is a multi-faceted activity that involves making observations; posing questions; examining multiple sources of information to see what is already known; planning investigations; reviewing what is already known in light of the student’s experimental evidence; using tools to gather, analyze and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations (www.NLISTinquiryscience.com).

**Interdisciplinary:** Of, relating to, or involving two or more academic disciplines that are usually considered distinct (www.thefreedictionary.com).

**Multidisciplinary:** Of, relating to, or making use of several disciplines at once (www.thefreedictionary.com).

**Pedagogy:** The art, science, or profession of teaching (www.mirriam-webster.com)

**Problem-based learning:** A method of instruction where problems are used as a catalyst for student learning. Students acquire content knowledge as they work to solve the unfamiliar problems that their tutors have presented.
**Project-based learning:** The use of classroom projects, intended to bring about deep learning, where student's use technology and inquiry to engage with issues and questions that are relevant to their lives. These classroom projects are used to assess student's subject matter competence compared to traditional testing (www.wikipedia.org).

**Reformer:** one that works for or urges reform (www.mirriam-webster.com).

**Research University:** An institution of higher learning that offers a full range of undergraduate, graduate, and doctoral programs, with a strong research program (The Boyer Commission on Educating Undergraduates in the Research University).

**Scholarship:** the character, qualities, activity, or attainments of a scholar (www.mirriam-webster.com).
Appendix 2: Sample STEM Problem-Based Learning Questions
from the University of Delaware

1. CHEM-103H

Saving for a Rainy Day
Written by Susan E. Groh

You've been invited to spend the weekend at your cousin's new cabin in the Poconos. She and her husband, having decided to "live simply", have constructed their home far from the beaten path, with an eye to being as energy efficient as possible. They've installed solar cells and collectors for generating electricity and heating their home, but are still trying to decide on the best way to trap and store energy for use at night and on cloudy days. They had planned to construct a tank containing some substance that can absorb the energy of sunlight, and then use that energy to provide heat for their home. They've found some plans for how to distribute the heat from such a storage reservoir throughout the house, but are still unsure about what materials to use for the tank and that substance. They'd originally thought of having a steel tank full of water, but are now intrigued by a magazine article that discussed the use of "phase-change materials" to store energy.

They show you some tables that appeared in the article.

Table 1. Heat Storage Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Specific Heat (Btu/lb/degF or cal/g/degC)</th>
<th>Density (lb/ft³)</th>
<th>Heat Capacity (Btu/ft³/degF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>1.00</td>
<td>62</td>
<td>62</td>
</tr>
<tr>
<td>Steel</td>
<td>0.12</td>
<td>490</td>
<td>59</td>
</tr>
<tr>
<td>Copper</td>
<td>0.09</td>
<td>555</td>
<td>50</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.22</td>
<td>170</td>
<td>37</td>
</tr>
</tbody>
</table>
Table 2. Properties of Phase-Change Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (lb/ft³)</th>
<th>Heat of Fusion (Btu/lb)</th>
<th>Melting Temperature (degF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glauber's salt</td>
<td>91</td>
<td>108</td>
<td>88 - 90</td>
</tr>
<tr>
<td>Hypo</td>
<td>104</td>
<td>90</td>
<td>118 - 120</td>
</tr>
<tr>
<td>Paraffin</td>
<td>51</td>
<td>75</td>
<td>112</td>
</tr>
<tr>
<td>Calcium chloride</td>
<td>102</td>
<td>75</td>
<td>84 - 102</td>
</tr>
</tbody>
</table>

The problem here is that neither your cousin nor her spouse have much of a background in science, and they don't know what to make of the data in these tables, and so can't proceed with their decision making. They're hoping that you might be able to interpret this, and give them some advice about choosing a heat storage system (both the tank material and the substance to be kept in it) that will enable them to store as much heat as possible, within a reasonable physical space. They'd like to be able to store enough energy for three day's use; the article gives an estimate of about 480,000 Btu as the thermal energy needed to heat a house similar to theirs for a day.

What advice would you give?

Preliminary Questions:

1. What do the data in these tables mean to you? Can you identify all of the terms and units? What information can you get from these?

2. What sorts of assumptions might you need to make to get started on your decision? Are there other data you think you need here?
2. CHEM-342 INTRODUCTION TO BIOCHEMISTRY, FINAL EXAMINATION

1. There are two parts to this examination. Each will take about 90 minutes.
2. There are 3 questions in Part I. Answer any combination of questions that totals 75 points. You may refer to your course reader, course notes, course handouts, and homework assignments.
3. While this examination emphasizes work done in this course since Spring Break, knowledge is not so conveniently compartmentalized. Therefore, you should feel free to use any relevant example from your experience, if it is appropriate.
4. Please write legibly and compose your answers so that you say what you mean.
5. If you finish Part I early, you may leave the room and relax until Part II begins around 5 P.M.
6. P.S. Don't forget to put your name on your blue book.

GOOD LUCK
CHEM-342 in the future might well include articles published in the 1990's that describe the first use of powerful genetic techniques, such as transgenic mice and site-directed mutagenesis, to study the biochemistry of HbS and sickle-cell anemia. Among the candidates for inclusion are the three whose abstracts appear on the following pages. Each article addresses learning issues raised by students this semester in response to articles we have read. For each, you will be asked to answers several questions.

ABSTRACT 1:
Science 247, 566-568 (1990)
Human Sickle Hemoglobin in Transgenic Mice
by T.M. Ryan, T.M. Townes, M.P. Reilley, T. Asakura,
R.D. Palmiter, R.L. Brinster, and R.R. Behringer

DNA molecules that contain the - and S-globin genes inserted downstream of erythroid-specific, deoxynuclease I super-hypersensitive sites were coinjected into fertilized mouse eggs and a transgenic mouse line established that synthesizes human sickle hemoglobin
(HbS). These animals were bred to -thalassemic mice to reduce endogenous mouse hemoglobin levels. When erythrocytes from these mice were deoxygenated, greater than 90 percent of the cells displayed the same characteristic shapes as erythrocytes from human cells with sickle cell disease. Compared to controls the mice have decreased hematocrits, elevated reticulocyte counts, lower hemoglobin concentrations, and splenomegaly, which are indications of the anemia associated with human sickle cell disease. [Note: An article describing very similar work by another research group appeared in Nature 343, 183-185 (1990) within a month after this article.] 1a. (10 points) What don't you understand about the work described? Make a list of clearly expressed learning issues that define what it is that you would need to look up and learn in order to understand the article. From your list, identify and justify the one learning issue that you feel is the most important.

1b. (10 points) In a clearly written paragraph or two, discuss the importance of the work described in the above abstract and relate it to one or more of the articles you have read this semester.

1c. (5 points) What do you think researchers would do with a strain of mice in which the red blood cells sickled?

1d. (5 points) If you were a member of an animal welfare review committee, what assurances, if any, would you want to have before you would approve the work described?

ABSTRACT 2:  
J. Biol. Chem. 269, 9562-9567 (1994)  
Role of 87 Gln in the inhibition of Hemoglobin S Polymerization by Hemoglobin F by K. Adachi, P. Konitzer, and S. Surry
Previous studies suggested that 87 Gln in hemoglobin (Hb) F is an important site for promoting inhibition of Hb S (26 Glu Val) polymerization by Hb F. We engineered and isolated the double mutant (Hb 26 Glu Val, 87 Thr Gln) using a yeast expression system and characterized polymerization properties of this modified tetramer in an effort to clarify the role of Gln at position 87 in inhibiting Hb S polymerization. Electrophoretic mobility and absorption spectra of this double mutant were the same as that of Hb S, while oxygen affinity was higher, and the effects of organic phosphates on oxygen affinity were reduced. The deoxy form of the double mutant showed a characteristic delay time prior to polymerization in vitro. The critical concentration for the double mutant was about 1.5 times higher than Hb S, and the delay and polymerization times were much longer than Hb S at the same hemoglobin concentrations. The logarithmic plot of delay time versus hemoglobin concentration for the double mutant showed a straight line that was intermediate between lines for AS and FS mixtures. These results and those of kinetics of polymerization of Hb S/double mutant mixtures indicate that substitution of Gln for Thr at 87 in Hb S prolongs delay time and inhibits polymerization, although the double mutant forms polymers like Hb S.

2a. (10 points) Draw a model of hemoglobin that conceptualizes what the Hb double mutant is. Use that representation to illustrate the phenomenon that the authors of this paper studied. You may provide a short narrative that explains your model.

2b. (10 points) In a clearly written paragraph or two, discuss the importance of the work described in the above abstract and relate it to one or more of the articles you have read this semester.

ABSTRACT 3
Effects of 6 amino acid hydrophobicity on stability and solubility of hemoglobin tetramers
The relationship between different amino acids at the 6 position of hemoglobin and tetramer stability was addressed by a site-directed mutagenesis approach. Precipitation rates during mechanical agitation of oxyhemoglobins with Gln, Ala, Val, Leu, and Trp at the position increased 2, 5, 13, 21 and 53 time, respectively, compared with that for Hb A. There was a linear relationship between the log of the precipitation rate constant and amino acid hydrophobicity at the 6 position, suggesting that enhanced precipitation of oxy Hb S during mechanical agitation results in part from increased hydrophobicity of Val. Deoxyhemoglobin solubility increased in the order of 6 Ile, Leu, Val, Trp, Gln, Ala, and Glu suggesting that hydrophobic interactions between 6 Val and the acceptor site of another hemoglobin molecule during deoxy-Hb S polymerization not only depend on hydrophobicity but also on stereospecificity of the amino acid side chain at the 6 position. Furthermore, our results indicate that hydrophobic amino acids at the 6 position which promote tetramer instability in the oxy form do not necessarily promote polymerization in the deoxy form.

3a. (10 points)
There are twenty different amino acids normally found in proteins. Site-directed mutagenesis enables biochemists to create protein molecules that might never be found in nature. For the chain of hemoglobin there are 19146 different single amino acid replacements that could be made by site directed mutagenesis. Why did the authors of this paper select the ones they did out of that enormous number of possibilities.

3b. (10 points)
In a clearly written paragraph or two, discuss the importance of the work described in the above abstract and relate it to one or more of the articles you have read this semester.

3c. (5 points) If you were doing the experiments described above, how would you go about measuring precipitation of hemoglobin in a continuously stirred solution?

Part II (Group Work)
[25 points total]
A major objective of CHEM-342 is to have you learn to recognize what you don't know and empower you to fill those gaps in your knowledge. The following question deals with the application of concepts normally covered in introductory chemistry and organic chemistry but often not understood well by students. As with the midterm examination, a group response is expected but not required. You may hand in a separate answer for separate credit if there is not consensus within your group.

4. (25 points),br> In the Pauling et al. paper on page 546, it states, According to titration data obtained by us, the acid-base titration curve of normal human carbonmonoxy hemoglobin is nearly linear in the neighborhood of the isoelectric point of the protein, and a change of one pH unit in the hemoglobin solution in this region is associated with a change in the net charge on the hemoglobin molecule of about 13 charges per molecule.

In Fig. 1 of Ingram's 1958 paper, about 16 moles of NaOH are consumed per mole of hemoglobin when it is digested with trypsin.

a. Both of these statements concern the titration of similar numbers of protons associated with hemoglobin at or near neutral pH. Show, with chemically relevant models of hemoglobin, where these protons are coming from in each case.

b. Assume that trypsin catalyzes the digestion of hemoglobin fastest at pH 8, where Ingram did his experiment, but can catalyze the same reactions more slowly at pH 7 and 9. Based on your analysis in part "a," what would Ingram's Figure 1 look like at pH 7 and at 9 compared to pH 8?

3. PHYS 202 GROUP EXAMINATION
Accident or Abuse?
Written by Barbara A. Williams
Police officers were called by officials at the Christiana Hospital in Delaware to investigate a possible case of child abuse. All injuries to children are now investigated by local authorities who are concerned about protecting children from subsequent incidents of child abuse. The following statement was made by a babysitter who brought the unconscious young child to the emergency room.

"Thomas was crawling around on the rug and playing with his toys. When he reached for a large metal truck, a prominent spark lasting 5 msec appeared between his fingertip and the object. His fingertip was about 2 mm from his toy truck when the spark appeared. After the flash, Thomas collapsed. I saw his burnt finger, and fearing a severe injury due to the spark, I rushed him to the emergency room".

The investigator understands currents as large as 0.001 amp produce a harmless mild tingling sensation at the point of contact. Currents in 0.01 - 0.02 amp range can cause muscle spasms. Any above 0.2 amp can be potentially fatal. On the day of the accident, the weather was cold and dry. Under these conditions, the air would have become conducting when the electric field reached 3 x 10^6 N/C. The investigator checks the hospital records and notes that the burned region on the child's fingertip is 10^-4 m^2.

* Is it possible for the child to become electrically charged based on the babysitter's statement? Explain using physics principles.

* Draw the child's fingertip and the region of the toy truck just before the spark appeared. Show the approximate charge distribution on both. Explain in words your diagram. (Assume that the truck is neutral.)

* Explain in words how you would determine the charge on the child's fingertip.

* Would the electric interaction described by the babysitter be harmful to the child? (Give a detailed quantitative explanation.)

* Estimate the resistance of the dry air between the toy truck and the child's fingertip. Is your estimate consistent with what you would have expected before making any of the previous calculations?
* Is there reason for the investigator to suspect foul play when she compares the babysitter's version of the incident and the conclusions she reaches after having applied physics principles to the problem? Explain.
Appendix 3: Further investigating STEM education at Brown - Sample Research Protocol

**Aims**

The purpose of this research is to better understand the attitudes toward education reform and science pedagogy among STEM professors at Brown University, and to identify trends in such attitudes based on department affiliation. In interviewing professors in three specific science departments, I hope to understand how different departments value teaching and how they structure and conceive of their introductory level courses. The first goal of this research is to identify whether there is a department-specific correlation between attitudes toward teaching and student attritions rates. The hypothesis is that those departments that are losing the greatest percentage of potential concentrators are those departments where students are most dissatisfied with the introductory level course, and so this research is aimed at better understanding if and how the quality of those introductory courses reflect departmental cultures toward teaching. The second goal of this research is to better understand departmental attitudes toward teaching in order to predict how recent Brown reports’ recommendations for change could be successfully worked into various department-specific cultures.

**Methodology**

This study will focus the Neuroscience, Chemistry, and Geology departments at Brown as three case studies of departmental attitudes toward science pedagogy and education reform. These departments were selected because of their diversity.

Neuroscience is a life science, while Geological Sciences and Chemistry are physical sciences. Neuroscience is a relatively large department, having graduated 59 undergraduates in 2007. Chemistry is a mid-size department having graduated 28 students in 2007. Geological Sciences is a small department having graduated 12
undergraduates in 2007. These three departments also have had mixed success in student recruitment. Enrolment in the Chemistry concentration has decreased over the last ten years, enrolment in the Geological Sciences concentration has increased slightly over the last ten years, and enrolment in the Neuroscience concentration has remained relatively stable. Furthermore, Critical Review course reviews suggest that these departments have different levels of success with their introductory courses, which is relevant given that a significant portion of attrition occurs soon after students complete the introductory course in a discipline. The introductory course in the Geological Sciences (Physical Processes in Geology) and in Neuroscience (The Brain: An Introduction to Neuroscience) have consistently received more positive reviews from students than the introductory course in Chemistry (Equilibrium, Rate, and Structure).

The participant population will include as many professors or lecturers in the aforementioned departments as are willing to participate. All professors and lecturers in Chemistry, Neuroscience, and Geological Sciences will be e-mailed directly, informing them of the project and asking if they are willing to consider participating in this research project.

When a professor agrees to participate in this research, I will ask them to set aside a one hour time block for us to meet. All interview questions will come from the list of sample interview questions prepared in advance and e-mailed out with the initial solicitation e-mail. Not every interviewee will be asked every question. The questions are meant to stimulate discussion, and which questions are addressed will depend on what the interviewee is most interested in talking about. The remaining ten minutes will be reserved for any remaining questions that either party might have.
Sample Questionnaire

Part 1: Teaching history

What is your job title?

How long have you been on the faculty at Brown University?

What courses have you taught in your time at Brown?

For how many years did you teach each of those classes?

Have you ever been on the faculty at another university? If yes, please describe how your experience teaching there was similar and/or dissimilar to your experience teaching here at Brown University.

Part 2: Identifying the problem

Approximately how many students take the introductory level course in your department, and approximately how many of those students end up pursuing degrees in your department?

For whom are the introductory courses in your department designed? How are those courses tailored to specific populations of students?

What are your impressions of student retention in your department?

What are the strengths of the undergraduate program in your department? In what way does the current program benefit students and faculty respectively?

In what way does your department’s undergraduate program need to change? Who would benefit from those changes?

Please describe how you see university and departmental politics and/or culture playing a role in science education reform at Brown University.

Part 3: Interdisciplinary Relationships

Are you currently or have you ever been engaged in any research projects with faculty in other departments? If so, please describe.

What do you see as the role of interdisciplinary learning in the undergraduate science programs at Brown University.
Have you ever taught a course at Brown University or elsewhere that you would describe as interdisciplinary? If so, please describe the course.

**Part 4: Developing a culture of reform**

How many courses are you required to teach? Do you think this requirement is appropriate, too light, too heavy?

How familiar are you with the Sheridan Center at Brown University? Have you ever consulted or worked with the Sheridan Center at Brown University?

How would you describe faculty attitudes toward teaching within your department?

**Part 5: Change**

Have you ever participated in a conference, workshop, or course about science education? How was this experience useful to you as a teacher?

Does the academic society affiliated with your discipline sponsor any education conferences? If yes, have you ever attended one of these conferences? What were your impressions of the conference?

Does your department have any funds available for education reform? If yes, have you ever tried to obtain such funds for a project? What was the project?

Have you ever tried to obtain funds from the University for a project to improve science education? If so, what was the source of those funds and how were they used?

Have you ever tried to obtain external funds for a project to improve science education?

If you could fund any project to improve science education at Brown University, to improve the undergraduate program within your department, or to improve one of your own courses, what project would be your priority?
Bibliography


15. Brown University: Task Force on Undergraduate Education. (2008). *The curriculum at forty: A plan for strengthening the college experience at brown [DRAFT].* Providence, RI:


Elizabeth Schibuk


