Facilitating Change in Undergraduate STEM Education

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Consider Professor Smith, who has been working in the chemistry department at Mid-Sized Research University (MRU) for 15 years. She has been a successful researcher, obtaining grants and publications at about an average rate for her institution. She has also been an innovative teacher who has attended several national conferences related to student-centered chemistry teaching.

She has had conversations about new teaching strategies with a small set of her departmental colleagues, as well as with a few faculty members from other science departments on campus, and has participated in a faculty learning community there. Smith sees the difference that student-centered teaching methods make to her undergraduates, and she has read enough research to know that student-centered instruction demonstrably improves student learning, attitudes, and retention in many STEM disciplines.

Smith thinks that there could be even greater benefits from this kind of instruction if each STEM undergraduate at MRU could take several introductory courses taught in a student-centered manner. She realizes that doing this would require substantial work but that there are external funding sources that could help facilitate this transition.

She finds that a national-level higher education foundation offers grants of up to $1M for innovative projects that work to improve undergraduate STEM education. The next deadline is in six months. Now, Smith has to put together a compelling plan that will be attractive to the funding agency and also will be likely to create lasting and sustainable change in her own and other STEM departments at MRU.

What are the important things that she needs to think about? What change strategies are likely to be successful? What are the barriers to sustained change? Who should be included in this process?
Modern efforts to improve STEM education build on fifty-plus years of funding and research in the United States, tracing back to major investments following the 1957 Soviet launch of Sputnik. Recent calls to improve STEM instruction have been based on multiple needs: to prepare STEM professionals, to address the shifting demographics of our society and the equity and access issues they raise, to ensure national security, to garner national prestige, to encourage economic development, and to address global issues such as climate change. Similar discussions are occurring in the European Union and individual countries worldwide.

Modern investment in STEM education has focused on the introductory sequences within disciplines. Introductory science courses such as Smith’s are a gateway both to STEM teaching and to various undergraduate STEM majors. By shifting these courses from an instruction- or teacher-centered to a learning- or student-centered paradigm, faculty can address high attrition rates, model best teaching practices (for all levels), and establish educational practice as a scholarly and culturally valued pursuit within the STEM disciplines.

Due to substantial research efforts over the last decades, we now know a lot about how students learn and about instructional strategies and curricula that can facilitate this learning. The National Research Council (Singer, Nielsen, & Schweingruber, 2012) has summarized key research findings on effective approaches in college science and engineering courses. The report enumerates principles that are pertinent to all disciplines:

1) Build on research about what students know and how they engage with materials;
2) Make classrooms interactive, both to engage students and to provide dynamic feedback in situ;
3) Require collaborative work;
4) Broaden courses’ educational goals to include improved conceptual understanding, problem-solving abilities, representations of findings, transfer of knowledge, metacognition, and appreciation for the field.
5) Leverage technologies to make the most effective use of students’ time, shifting from information delivery to sense-making and practice in class.

As a recent White House report (President’s Council of Advisors on Science and Technology, 2012) puts it, “Thinking like a STEM professional requires acquisition of information, habits of mind, skills, and an identity embedded in a STEM discipline. Such diverse attributes are unlikely to be learned most effectively through one mode of teaching.”

But despite having significant knowledge of effective practices, along with curricular and pedagogical resources, efforts to transform introductory sequences have met with only modest success. While we may know what to do, we do not know how to enact and sustain these reforms at scale. What we need is a framework for understanding STEM instructional change.

We propose such a framework to provide a tool for those engaged in educational transformation at the undergraduate level, particularly within STEM education. We summarize findings from an interdisciplinary literature review, introduce a typology of change strategies, and use these to make recommendations for mechanisms of change.

**A Framework for STEM Change**

To establish a foundation for our work, we conducted a literature review of journal articles published between 1995 and 2008 that describe efforts by change agents to improve instructional practices used in undergraduate STEM education, as well as articles focused on the development of strategies or models relevant to such improvement efforts. The review identified four distinct types of change strategies, as defined by their goals.

**Figure 1**

**Four Categories of Change Strategies. (Adapted from Henderson, Beach, & Finkelstein, 2011)**

<table>
<thead>
<tr>
<th>Prescribed</th>
<th>Emergent</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Disseminating: CURRICULA &amp; PEDAGOGY</td>
<td>II. Developing: REFLECTIVE TEACHERS</td>
</tr>
<tr>
<td>Goal: Teach individuals about new teaching conceptions and/or practices.</td>
<td>Goal: Encourage individuals to develop new teaching conceptions and/or practices.</td>
</tr>
<tr>
<td>30% of articles</td>
<td>34% of articles</td>
</tr>
<tr>
<td>III. Enacting: POLICY</td>
<td>IV. Developing: SHARED VISION</td>
</tr>
<tr>
<td>Goal: Create environments/structures that require new teaching conceptions and/or practices.</td>
<td>Goal: Empower stakeholders to collectively develop new environments/structures that support new teaching conceptions and/or practices.</td>
</tr>
<tr>
<td>28% of articles</td>
<td>8% of articles</td>
</tr>
</tbody>
</table>
Categorizing Change Strategies

The categories of change strategies (Figure 1) are based on the combined answers to two questions. The first is, “What is the primary aspect of the system that the change strategy seeks to directly affect—individuals or environments and structures?” Change strategies focused on individuals seek to change the beliefs and behaviors of instructors, assuming that they act as free agents. For environments and structures, the change strategy targets the environments that are assumed to influence the actions of individuals.

The second question is, “To what extent is the intended outcome for the individual or environment known in advance—is it prescribed or emergent?” For prescribed outcomes, change agents define in advance what kinds of behaviors or mental states in individuals or groups they want to develop. For emergent outcomes, those behaviors or mental states are determined as part of change process, since people involved in the change have important information needed to define the outcomes.

The following sections briefly describe each type of change strategy and characteristics of successful strategies within that category. Cross-case exemplars are offered to illustrate how initiatives can incorporate multiple strategies.

Weaknesses of the Current State of Scholarship

Three distinct research communities are working to create change in undergraduate STEM education. Disciplinary-based STEM education researchers are typically situated in STEM departments, frequently in a college of arts and sciences or engineering. But sometimes these researchers are disciplinary STEM specialists in a college of education. Faculty development researchers are generally in centers for teaching and learning. Higher education researchers are usually to be found in departments of educational leadership in a college of education but occasionally in university administration.

The literature review identified three weaknesses in the current state of scholarship related to improving the use of change strategies in undergraduate STEM education. It is unlikely that much progress will be made unless these weaknesses can be addressed.

No communication among the three research communities
The three scholarly communities rarely share ideas. The work of these groups is deeply complementary, and regular discourse between them would yield better understanding and theory regarding change in teaching and learning. However, each of these groups has its own distinct professional societies, journals, and disciplinary norms, which hamper such discourse.

Scholarship does not build on previous work
An important way to improve the knowledge base is to build current work on earlier research. In our literature review, only half (49.7%) of the articles clearly connected their scholarship to previous work. And even those citations are generally confined to a single disciplinary community.

Lack of evidence to support claims
A key feature of scholarly research is to support claims with evidence. Of the articles in our literature review that described the implementation of a change strategy, two-thirds claimed that the strategy studied was successful. However, we found that few articles (only 21.0%) actually presented strong evidence to support claims of success or failure of the strategy studied.

Change strategies focused on individuals seek to change the beliefs and behaviors of instructors, assuming that they act as free agents.

For environments and structures, the change strategy targets the environments that are assumed to influence the actions of individuals.
Individual/Prescriptive: Disseminating Curriculum and Pedagogy

Most prevalent in the literature are change strategies focused on individual instructors. With a prescriptive focus on individuals, change agents try to impart their vision of good curricula or pedagogy to faculty and to motivate faculty adoption, providing varying levels of support. Common change strategies in this category include workshops and talks.

The strength of this kind of strategy is that to develop and test curricular materials or teaching approaches is beyond the skills and available time of most faculty. On the other hand, faculty may use the curricula or new practices inappropriately or not at all. Also, many of the most effective teaching approaches conflict with traditional university environments, which create extrinsic barriers to their use. These barriers include expectations that courses cover a lot of material, lack of instructor time and incentive to make changes, departmental norms, student resistance to new teaching methods, and class size and room layout that do not support interactive teaching (Henderson & Dancy, 2007).

Successful strategies focused on disseminating curriculum and pedagogy typically involve more than one of the following components: coordinated and focused efforts lasting over an extended period of time (typically one semester or academic year), use of performance evaluation and feedback, and a deliberate focus on changing faculty conceptions rather than behaviors.

Individual/Emergent: Developing Reflective Teachers

With an emergent focus on individuals, change agents seek to encourage faculty to use their own knowledge and experience to improve their instructional practices. This strategy is designed to lead to instructor-identified changes. The change agent offers varying levels of support and control.

The strength of this strategy is that faculty who develop their own instructional strategies have ownership of the new approaches. The emergent design of the new strategies means they are a good match for the instructor and the local environment. On the other hand, most universities do not reward the focus on teaching required of faculty to develop their own instructional strategies, and faculty-developed materials may not be as strong as those developed and tested by educational researchers.

Successful strategies in this category tend to focus on individual or group consultation or communities that share ideas and provide support for individual change. Two key features of successful approaches in this category are for change agents to provide feedback to instructors and to encourage instructors to reflect on their practices.

Environments/Prescribed: Developing Policy

Less prevalent in the literature are descriptions of efforts to develop environments (e.g., rules, reward systems, reporting requirements, support structures) to promote the use of improved instructional practices. While dissemination-based interventions that focus on individuals use internal motivation as the primary mechanism for change, here significant external incentives or requirements are used. The primary change-agent role is to direct, lead, or manage.

The strengths of strategies in this category are that traditional environments are often barriers to change. Policy changes can also often be implemented relatively quickly to address and minimize those barriers. On the other hand, because of the loose coupling present in university environments, top-down enforcement of change is difficult. This makes it relatively easy for faculty to subvert policy changes.
that they see as entailing extra work or limiting their academic freedom.

One important conclusion from articles in this category is that power alone, in the form of “top-down” policy implementation, is insufficient to leverage change. Successful strategies within this category promote a move away from strict top-down mandates and from assumptions that single policy solutions exist for multiple departments or disciplines within an institution or among institutions. Policies that take into account and work within local (departmental or institutional) contexts are more likely to be successful.

**Exemplar: Combining Dissemination with Developing Policy**

Brent and Felder (2003) describe the SUCCEED faculty-development program, which involved a coalition of eight institutions in the Southeastern United States. In the late 1990s, this program sought to scale-up faculty use of a set of innovations in engineering courses that faculty had previously developed.

The program had two main foci. One was the dissemination of these ideas through a series of workshops. The other was to make targeted changes in the institutional environment that would favor the use of these new ideas.

Two important environmental changes were to have a faculty member within engineering designated to coordinate faculty-development activities and to provide institutional incentives for teaching improvement. A web survey administered to program participants at the participating institutions found that most faculty had participated in the faculty-development program, had increased their use of the targeted instructional activities, and perceived that the change had led to improved student learning.

**Environments/Emergent: Developing a Shared Vision**

In this type of intervention, the department, institutional unit, or institution (and, on occasion, even supra-institutional entities) develops a collective vision for new modes of instruction. Stakeholders help shape a new culture and determine what types of environments or structures will be necessary to support it. The change agent’s role is to bring individuals together to work towards collectively envisioned change.

The strength of strategies in this category are that they recognize that group norms are a key change lever and are not easily changed by policy means. These strategies also incorporate the specialized knowledge of stakeholders throughout the system. On the other hand, there is currently very little concrete guidance available for change agents who wish to use this type of strategy.

Although this was the category that had the smallest number of articles in our literature review, the ideas in this category of collective decision making based on distributed knowledge in a system and individual buy-in are consistent with recent trends in the organizational-change literature and that of community building.

**Exemplar: Creating a Shared Vision and Developing Reflective Teachers**

A team of faculty and graduate students at the University of Maryland (Marbach-Ad, et al., 2007) adapted a proven model for productive work within a university setting, the research group, to solve teaching problems. The members of this group share a research focus on host-pathogen interaction and are responsible for teaching seven large-enrollment microbiology courses. Beginning in 2004, the team agreed upon the fundamental concepts of the set of courses, chose

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anchor pathogens that would be used throughout the courses, and adopted the university’s course-management system as a platform for sharing resources across courses. They also collaborated to conceptualize, create, and test an assessment tool to measure student learning across the courses.

While the goals were established early, the mechanisms and outcomes were collectively arrived at rather than prescribed. Individual faculty were supported in changing their teaching approaches in ways that fit their own courses, in line with the vision the group had developed.

Change agents typically operate within one of the four categories; very few articles described strategies that cut across or encompass multiple types. Reformers were considerably more likely to aim at changing individual faculty than environments or structures. The articles were more evenly divided between working toward prescribed outcomes and developing emergent outcomes.

Although we are often asked to identify the “best” change strategy, we found very little empirical research that compares similar change strategies in different contexts or different change strategies in similar contexts. More importantly, the local context and goals of change initiatives vary so widely that blanket statements about how to create change are likely to be useless. Instead, what this framework offers is a set of perspectives to consider when planning for change.

**Exemplar: Incorporating All the Quadrants**

An increasingly popular strategy for transforming STEM education is to focus on disciplinary identity and practice. In a study of the week-long National Academies Summer Institute on Undergraduate Education in Biology, Pfund and colleagues (2009) describe their efforts to transform STEM education through a comprehensive faculty-development program.

This effort, which has resulted in participants making significant changes in their teaching practices and becoming change agents themselves, begins with the developing-reflective-teachers quadrant but recognizes the critical nature of developing policy locally and nationally. Locally, institutions give support to faculty participants, including sending a number of them to the institute and providing funds for their on-going work.

Nationally the efforts focus on increasing tangible support for undergraduate teaching as a valued pursuit in the field of biology (as endorsed by the Howard Hughes Medical Institute and the NAS). Components of this program also include the use of specific research-based curricular materials and the collective decisions by groups of faculty regarding what will work in their local contexts.

**Back to Smith**

As a STEM faculty member, it is quite likely that Smith will tend to think of change strategies involving dissemination of prescribed curricula or pedagogies. They are by far the most common approach used STEM educational researchers and are likely to be what she has experienced. Thus, the first step in the change process is to become familiar with the other strategies and consider the strengths and weaknesses of each type for her situation.

Although one might think that a purely emergent change strategy is likely to be most successful, as is typical, Smith has a general direction in which she would like things to move (i.e., towards student-centered teaching). Thus, she is likely to favor a degree of prescription. But even though she may be tempted to give seminars about the benefits of student-centered instruction, it is probably not best to start by providing solutions to people who do not think they have a problem. It is likely to be more effective to have a series of discussions to better understand the concerns that faculty are having about their teaching, what groups on campus are already working to address these issues, and what the history of similar efforts has been. In short, if Smith wishes to shape the system, she must first understand it.

Next, she might engage in a variety of activities that help bring about the changes she seeks, which will become solutions to the challenges that were identified collectively. By including others and understanding her local context, she will create more local buy-in, be able to advocate for changes that are appropriate to the context, and draw on resources that are available.
CONCLUSIONS

In this essay we have sought to provide a few tools for the Professor Smiths of the world—that is, for those seeking to enact sustainable and scalable change in the ways we support undergraduate student learning.

From the literature review, it is clear that a successful change strategy should allow for a mixture of emergent and prescribed outcomes and pay attention to multiple levels of context, from the individual faculty to the environments and structures within which faculty work. We believe that the
most successful work on instructional improvement will emerge from multi-category, multi-disciplinary, multi-institutional, and multi-national research and experimenta-

While there is still much to learn about effective models for change in STEM education, we already know a great deal about suites of efforts that seem to work. Such awareness is timely, given current pressure to substantially transform undergraduate instructional practice in STEM. Whether in the form of calls from the White House and state legislatures, economic pressures to develop efficient instructional models, or competition from online and hybrid models, there are demands on institutions of higher education to improve and demonstrate their impact on students.

These pressures and demands will be increasing in coming years. If we, as agents within institutions of higher education, do not respond to them, others will. And then, they will define these goals and methods for us. 

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**Resources**


**Websites**

- The Association of American Universities’ Undergraduate STEM Education Initiative to increase the number of undergraduate STEM majors: [www.aau.edu/WorkArea/showcontent.aspx?id=12592](http://www.aau.edu/WorkArea/showcontent.aspx?id=12592)
- Northwestern University’s Searle Fellows Program: [http://www.northwestern.edu/searle/programs/facultyprograms/searle_fellows_program.html](http://www.northwestern.edu/searle/programs/facultyprograms/searle_fellows_program.html)
- The National Academies Summer Institute on Undergraduate Education in Biology: [http://www.academiessummerinstitute.org/](http://www.academiessummerinstitute.org/)