Increasing the Impact and Diffusion of STEM Education Innovations

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Introduction

There have been many calls for the reform of introductory Science, Technology, Engineering and Mathematics (STEM) courses based on extensive research demonstrating the significant limitations of traditional, lecture-based instruction. These calls have led to large expenditures of time and money on research and development aimed at improving STEM instruction.

Significant empirical research has shown that student learning can be improved when instructors move from traditional, transmission-style instruction to more student-centered, interactive instruction [1,2]. However, although tremendous amounts of time and money has gone into developing and disseminating research-based pedagogy and curriculum, there currently exists a substantial gap between knowledge of 'best practice' instructional methods within the community of educational researchers and the teaching practices of typical STEM faculty. The biggest barrier to improving STEM education is not that we lack knowledge about effective teaching. **The biggest barrier to improving undergraduate STEM education is that we lack knowledge about how to effectively spread the use of currently available and tested research-based instructional ideas and strategies.**

It is not enough to simply conduct research and develop high quality teaching materials. High quality research and curriculum development is only valuable if it is actually used. We have been involved in several projects aimed at better understanding why research-based reform has not had as much impact as might be expected given the expenditures of time and money. In the paper that follows, we detail some of our findings and offer recommendations based on these findings. Although the majority of our work has been in the field of Physics, we believe that the ideas discussed here are also relevant to Engineering and other STEM disciplines.

The impact of change strategies on faculty practice

Before we delve into a discussion of how to improve reform efforts, it is helpful to first consider the impact of past efforts. Until recently there has been very little knowledge about the degree to which STEM faculty know about or use instructional strategies that are consistent with the research base. However, survey-based research in Engineering [3], Geoscience [4], and Physics [5,6] now allows us to estimate the impact of the current wave of change efforts, which we roughly characterize as the last two decades. During this time the NSF and other funding sources have provided substantial support for

Table 1. Results from three recent web surveys

	Engineering [3]	Geoscience [4]	Physics [5,6]
Respondents	257 engineering department chairs (16% response rate)	2207 geoscience faculty (39% response rate)	722 physics faculty (50% response rate)
How innovative instruction was framed	7 engineering education innovations (e.g., Design projects in first year engineering courses)	Frequency of use of 9 traditional and interactive instructional techniques (e.g., traditional lecture, small group discussion)	24 named research-based instructional strategies (e.g., Peer Instruction)
Level of knowledge	On average, department chairs are aware of 82% of the strategies	N/A	87% of faculty know about one or more of the strategies
Level of use	On average, department chairs report that 47% of the innovations are used in their department	More than 50% of faculty report using interactive techniques in their classes at least weekly	48% of faculty report using one or more of the strategies

these efforts. Table 1 shows the results of these three independent surveys in terms of faculty knowledge about alternative teaching strategies and faculty use of these strategies. On the surface these results indicate that faculty are largely aware of research-based instructional strategies and, although there is a significant gap between knowledge and use, many faculty report using these strategies.

While we are encouraged by these results, there are strong indications [5,6] that these results significantly overestimate the actual situation, especially with respect to the level of use. For example, in the physics survey we not only asked respondents to identify instructional strategies that they used, but we also asked them to describe their frequency of use of a number of more specific instructional activities (e.g., the use of small groups). For several innovative instructional strategies we had significant numbers of self-reported users to be able to compare the frequency of use of specific instructional activities to the frequency suggested by the strategy developer. It was very unusual (6% -21%, depending on the level of fidelity sought) for self-reported users to report instructional activities consistent with those advocated by the developer [6]. We also conducted follow-up interviews with 72 survey respondents to the physics survey [7,8]. Although the analysis process has not yet been completed, we have clearly found that an instructor's characterization of their level of knowledge and use (or non-use) of a particular strategy is not reliable. For example, we have found self-described users of the Peer Instruction instructional strategy who knew little to nothing about the strategy [8] and self-described non-users who knew much about the very specific ideas advocated by the developer and used the majority of features of a formal implementation. Thus, we need to find better ways to talk about these research-based instructional strategies and we should be cautious about giving much weight to self reports of knowledge or use of a particular strategy.

Knowledge and interest does not necessarily impact practice

The survey results presented above suggest that faculty are generally aware of research-based ideas (even if their knowledge is somewhat fuzzy). There is also evidence that faculty are, at least in principle, interested in implementing these strategies. For example, in the physics web survey, after asking faculty to rate their knowledge and use of the 24 named instructional strategies we asked them if they were interested in using more of these sorts of strategies. Seventy percent of respondents said 'yes'. However, the surveys, as well as our other studies [9,10] indicate that having knowledge of an innovation and a desire to use it does not necessarily translate into use.

The physics survey respondents who indicated interest in using more strategies were then given a text box and asked "What prevents you from using more of these strategies?" By far the most common reason, mentioned by 53% of those answering the question, was a lack of time [5]. Typically, the respondent was referring to the extra time it would require to learn about a strategy and then effectively implement the changes, though time in class to complete activities was also a common concern. Time is one of a set of situational factors that instructors see as constraints preventing the use of alternative instructional strategies [9]. We have consistently found that situational factors play a significant role in the gap between knowledge and use.

A summary of the most salient situational constraints identified in an interview study is given below (adapted from Ref. 9).

Expectations of Content Coverage**:** Instructors may forgo research-based methods that are geared toward deep understanding if they feel they must cover a lot of material. Likewise, they may change their instruction if this expectation is diminished.

Lack of Instructor Time**:** Instructors are sometimes too busy with large teaching loads and/or research responsibilities to have the time to learn about and integrate new techniques.

Departmental Norms**:** If other members of the department are integrating research-based methods it is easier for instructors to do so as well. It is much more difficult if traditional methods are the norm and there are no local role models to follow or offer supportive.

Student Resistance*:* Instructors frequently cite poor student study skills or work ethics as limiting their ability to use alternative instructional strategies. Additionally, they believe students often do not support research-based methods. In particular, they do not like to interact with each other and are often not prepared to think independently.

Class Size and Room Layout: Many of the instructors indicated that they worked in departments where they were expected to teach large numbers of students in lecture halls with seats bolted to the floor. They indicated that these characteristics made it harder to use many research-based methods that focus on interactivity, cooperative learning, and formative assessment.

Time Structure**:** Semesters are of a fixed length of time and do not allow for individual differences in learning needs. Also, since students are taking other courses the time they have available for one course is limited.

The dangers of inappropriate assimilation

Most instructors do not use materials "as is". They recognize that no set of instructional materials, no matter how carefully developed, will match the constraints of their specific classroom situation and their personal preferences and skills. Therefore, instructors must have the knowledge, skill, and confidence to customize the new instructional strategy to their own situation; "there is no way to avoid the local reconstruction of the practice [instructional strategy], as local staff make sense of it in their own context" (Ref. 12, p. 33).

Because of the conflicts with the current norms (both personal and situational), implementation of innovations may keep some of the surface features of an innovation, but remain essentially traditional instruction. For example, our research suggests that instructors may implement Peer Instruction [13], but without the peer interaction component [14,15]. This allows them to streamline their lecture and maintain a passive classroom, while appearing on the surface to have implemented a research-based innovation. Similarly, Boice reports that new college faculty self-described student-centered instruction was only confirmed by observations in about half of the cases [16], indicating that these faculty may

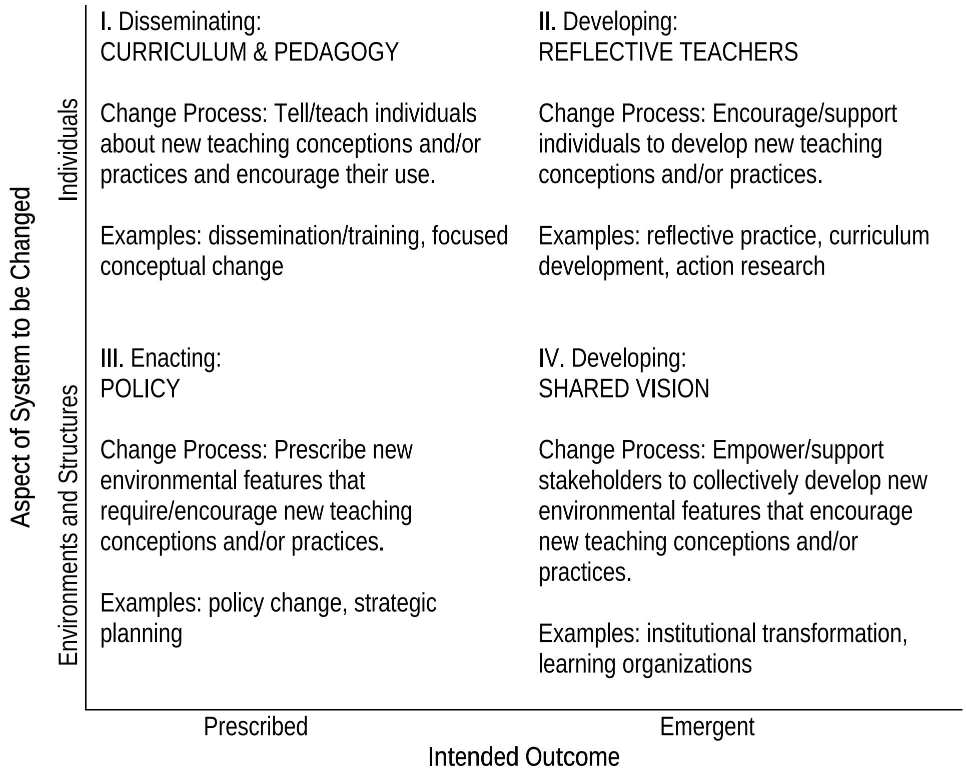

Figure I. *Overview of Four Categories of Change Strategies*. Adapted from ref. 22.

have assimilated the ideas of student-centered instruction into their mental models of instruction such that some aspects that conflict with the existing cultures are modified to align with these cultures. We have developed the term inappropriate assimilation to describe this type of "adoption" [15]. Innovations requiring fundamental changes appear to be quite susceptible to inappropriate assimilation [12,17-20]. One unfortunate result of this phenomenon is that instructors who think that they have adopted an instructional strategy, but have really inappropriately assimilated it into their prior instructional practices, may conclude that the strategy is ineffective.

Summary

Recent efforts to spread the use of research-based instructional strategies by faculty who teach undergraduate STEM courses has met with some successes and many failures. Currently, most faculty know about these alternative instructional strategies and appear to value them. On the other hand, the level of use of these strategies remains low and many faculty who use these strategies modify them to be more like traditional instruction. In the following section we discuss some ways that change agents might have more of an impact.

How could change agents have more impact?

Throughout this section we will make use of a framework of four core change strategies [21-23]. This framework was developed based on a literature review of 192 journal articles focused on efforts by change agents to improve instructional practices used in undergraduate STEM courses.

The four categories of change strategies (Figure 1) are based on the combined answers to two fundamental questions that emerged from analysis of articles. The first question is, "What is the primary aspect of the system that the change strategy seeks to directly impact (individuals or environments and structures)?" For *individuals*, the change strategy seeks to directly impact the beliefs and behaviors of instructors, assuming that they act of their own volition. For *environments and structures*, the change strategy seeks to impact 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 (prescribed or emergent)?" For *prescribed* outcomes, the change agent knows upon initiating a change process what kind of behavior or mental states in individuals or groups are expected and sought, driven by the assumption that the change agent has the key knowledge needed to define the outcomes. For *emergent* outcomes, the end state in terms of behaviors or mental states are determined as part of change process, with the assumption that those involved in the change have important information needed to define the outcomes.

Of the four categories of change strategies, STEM change agents strongly favor the individual and prescriptive category (Disseminating Curriculum and Pedagogy). This emphasis on development and dissemination is evident in much of the discourse related to STEM educational change which places substantial emphasis on the development and testing of specific instructional innovations. Once shown to be successful by their developer, these innovations are then disseminated to instructors who are expected to use them with some degree of fidelity. The instructor is not an important part of the development of these strategies and is often considered to be a barrier to educational change [12,24-27]. As an example, consider the model of curriculum development and dissemination described in a recent program solicitation of the NSF Course, Curriculum, and Laboratory Improvement (CCLI) program:

> "The CCLI program is based on a cyclic model of the relationship between knowledge production and improvement of practice in undergraduate STEM education. The model is adapted from the report, "Mathematical Proficiency for All Students" (see http://www.rand.org/publications/MR/MR1643/). In this model, research findings about learning and teaching challenge existing approaches, thus leading to new educational materials and teaching strategies. New materials and teaching strategies that show promise give rise to faculty development programs and methods that incorporate these materials. The most promising of these developments are first tested in limited environments and then implemented and adapted in diverse curricula and educational institutions. These innovations are carefully evaluated by assessing their impact on teaching and learning. In turn, these implementations and assessments generate new insights and research questions, initiating a new cycle of innovation." From ref. 28.

We believe that this development and dissemination change model has persisted for so long despite a lack of proven success because it makes intuitive sense. A change agent might imagine that the development and dissemination model would be most effective because it places much of the burden on the change agent to develop innovative strategies and materials. Conducting educational research and developing new curricular materials requires considerable time and expertise that typical faculty may not possess. Therefore these tasks are delegated to change agents who develop materials and then disseminate the materials directly to faculty. The assumption is that the faculty will be convinced to use these new instructional materials and strategies once they are shown data demonstrating that these new methods produce improved student learning compared to traditional instructional methods.

The development and dissemination change model has been reasonably successful at increasing awareness and interest in research based innovations. However, it is not effective at changing practice. This is not surprising since the model implicitly assumes that knowledge and interest are sufficient for change.

Toward a more effective change model

What would a more effective change model look like? Although more research is needed to answer this question with certainty, our current understanding does offer some guidance. The framework of change strategies described above suggests that, since STEM reformers have already focused significant attention on development and dissemination, the most promising new directions are likely to be found in strategies that allow for emergent outcomes as well as strategies that lead to structural changes.

Develop change strategies that allow for emergent outcomes: Faculty as reform partners

There are two important participants in instructional change. One is the instructors who are interested in or being asked to change their instruction. The other, change agents, are curriculum developers or professional development providers who provide information, materials, encouragement, etc. to help the instructors. We identified four types of interaction between external change agent and instructor in the change process (Figure 2). Although change agents typically operate on the adoption/adaptation end many faculty would prefer to collaborate in some form of reinvention [10]. Instructors recognize that an instructional package created elsewhere will necessarily have to be reworked to fit in the unique local environment.

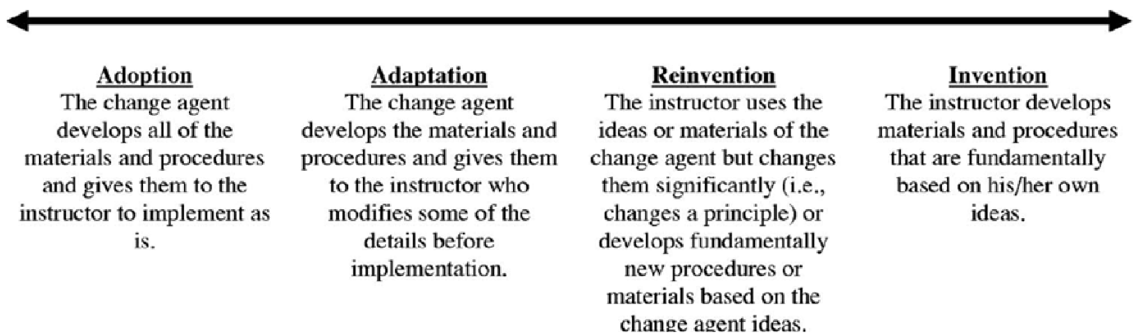

Figure 2. *Adoption-Invention Continuum*. From Ref. 10, p. 81.

Faculty want and expect to be partners in the reform process. However, faculty lack the expertise of education researchers and may develop materials in ways that are not consistent with effective outcomes. This often leads change agents to discredit faculty as true reform partners and to instead treat them as receptacles of reform. When viewed from certain perspectives, this division of labor that treats educational researchers as developers and faculty as implementers appears quite sensible. However, it also appears that most faculty have a strong feeling of ownership over their teaching that makes this division of labor problematic. **We do not expect any reform effort to be successful unless it involves faculty as meaningful participants**.

Below we list specific suggestions to help build bridges with faculty in the change process.

1. P*rovide easily modifiable materials.* Moving toward the invention side of the adoption-invention continuum means that instructional materials and designs should be developed with the expectation that faculty will engage in local customization. Faculty should be treated as participants in the development process and be given the opportunity to adopt materials for their local environments. In addition, providing instructors with easily modifiable materials communicates to them that they can and should use their own expertise to appropriately integrate the materials into their unique teaching situations..
2. *Focus on the dissemination of research ideas in addition to curriculum.* If faculty are going to modify curriculum effectively, they need to understand both *what* works (details) as well as *why* it works (principles). For example, although many physics faculty now have a copy of the book describing the instructional strategy of Peer Instruction [13] and many have begun using some of the associated conceptual questions, they are less aware of the research evidence that learning is primarily a social activity (e.g., as summarized by Redish in ref. 29, p. 39) and tend to drop the peer-peer interaction part of Peer Instruction [15]. Without an

understanding of the social importance of learning, it is easy for an instructor to reinvent peer instruction in a way that is likely to reduce its effectiveness. On the other hand, once an instructor understands the importance of social interactions for learning, they may be more likely to incorporate this aspect into their own reinventions or inventions.

3. *Emphasize personal connections over data presentation.* Reform efforts often focus on producing written materials for distribution, with an emphasis on data showing the effectiveness of the innovation. However, our preliminary analysis of interviews with physics faculty suggest that faculty who adopt an innovation typically learn about it and come to try it through dynamic social interactions (i.e. colleagues or workshops), rather than dissemination literature [7]. They do turn to the literature for additional information and support, but generally only after they have had some other avenue of exposure. Additionally, while the interviewees did often mention supportive data, this data was generally only a confirmation of what they already believed and not a factor that caused them to change their minds about an innovation that they did not initially believe would work. Faculty generally try new ideas for more intuitive reasons; they feel that their current approach is not working and the innovation makes sense. Data is still important as it helps faculty feel confident in their efforts to be more interactive and support them as they justify their diversion from the norm to their colleagues but data collected elsewhere does not typically cause faculty to change their minds one way or the other.

There is evidence that reform efforts centered on informed reinvention and invention can be successful. As an example, consider the Modeling Physics project at Arizona State University (http://modeling.asu.edu). This project is not a curriculum but rather a method of teaching based on the development of scientific models, in contrast to the traditional approach which is organized around topics. Dissemination focuses on helping teachers understand the modeling approach and why it is effective rather than on distributing specific curriculum. The project was intentionally designed from the beginning to treat teachers as partners [30]. Over time small teams of former workshop participants and practicing teachers have developed curricular materials based on the modeling approach. After review by an expert modeler, these materials are posted on a password-protected webpage and provided to all teachers who are, in turn, encouraged to modify the materials and share their modifications. Additionally, teachers using the modeling approach have formed a community with an active listserv which is used to support teachers having difficulty implementing the method and to allow teachers at similar schools to share the ways in which they have successfully adapted the method to their unique situation.

From a dissemination point of view, modeling has been exceptionally successful. As of this writing, more than 2000 high school teachers nationwide have participated in at least one 15-day modeling workshop. Of the teachers who participated in the full two-summer program, more than 90% indicated that it had a highly significant influence on the way they teach [31].

Develop change strategies that shape the system as well as the faculty

As discussed above, STEM change agents typically focus their efforts on changing individual faculty through various means of dissemination and persuasion. We suggest that dissemination activities should place more emphasis on understanding the local environment in which instructors teach and how that environment impacts their ability and inclination to be innovative. **Most faculty work in institutions where structures have been set up to work well with traditional instruction. Thus, there are many environmental barriers to instructional innovations**.

We propose a model to describe how individual and situational characteristics relate to instructional practices (Figure 3). In this model, individual characteristics consist of an instructor's conceptions (i.e., beliefs, values, knowledge, etc.) about actual or possible instructional practices. Situational characteristics consist of all aspects outside of the individual instructor that impact or are impacted by the instructors' instructional practices. All of the barriers described in the previous section are situational characteristics, but situational characteristics may also include other things such as availability of instructional resources, institutional reward system, and disciplinary expectations. According to the model, practice is consistent with conceptions when situational variables support the practice but may be inconsistent when situational variables are in opposition to a particular practice.

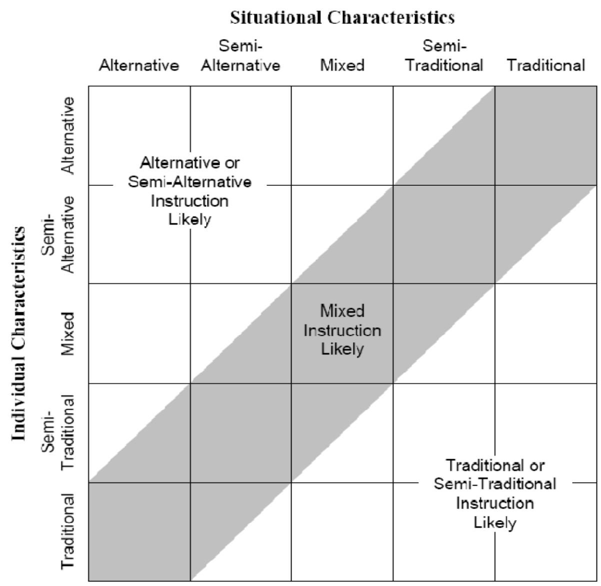

Figure 3. *Model for predicting behavior based on individual and situational characteristics*. From Ref 6, p. 10.

Other studies of college science faculty [32,33] and non-science faculty [34,35] agree with this model and suggest that situational factors have a substantial influence on instructional choices. The problem for advocates of reformed teaching, however, is that that although this influence can be in the direction of research-based instruction it is typically in the direction of traditional instruction. As described earlier, the development and dissemination model of change has resulted in change agents focusing the majority of their efforts on moving instructors' individual tendencies to become more alternative. Rarely does this change model focus on the situational constraints facing faculty or on ways to work with faculty/administrators/society to overcome these constraints. This is a significant shortcoming of the development and dissemination change model.

A greater emphasis needs to be placed on attempting to understand, classify, and change the situational characteristics that appear to play an important role in inhibiting changes in instructor practice. If many important barriers to the use research-based instruction are situational, then it is important for dissemination efforts geared toward individual instructors to acknowledge these barriers and help instructors find ways to overcome them or cope with them. Many of the reforms suggested by educational research are difficult to implement. Yet, many innovations are presented as if significant improvements are possible by following the "simple" suggestions of the curriculum developer.

The first step toward overcoming situational barriers is to simply acknowledge the reality of the difficulties instructors will face. Instructors then need to be provided with the information and tools to anticipate possible implementation difficulties due to situational barriers (for example, the chairs being bolted down, the class size being large, pressure to move too fast due to content coverage, the many years students have spent learning that school is about passively collecting facts). The question for the research community becomes; how can we help instructors to gain an awareness of the situational barriers they will face? And, once instructors identify these barriers how can they go about changing them.

In addition, change efforts should seek, whenever possible, to find ways to change the situation. For example, research suggests that department-level initiatives and departmental leadership can have a significant impact on the type of teaching within the departmental [36-38].

Summary

Change agents need to look for ways to enlarge their repertoire of change strategies. More productive change strategies will likely involve having faculty play larger roles in the change process (via. more emergent outcomes) and focusing attention on understanding and removing the environmental barriers to instructional reform.

Future directions for research and policy

In this section we identify several areas of research that we believe will help to improve the impact and diffusion of STEM education innovations.

Explicitly study change strategies.

There is a lack of research on the study and improvement of change strategies in STEM. We believe that this dearth of research has allowed the development and dissemination model of reform to remain as the implicit or explicit model behind STEM change strategies despite its lack of proven success.

Some may argue that a poor record of success is no reason to think that the development and dissemination change model is not effective. Rather, the problem is that change is just difficult and slow and we should not expect large impacts from our change efforts. The argument that change is just slow is problematic for several reasons. First, there are examples of sweeping change in education, such as the move toward high-stakes testing, which have not been slow. Under the right circumstances, change can and does take place much faster than the current change in STEM toward less lecture-based teaching. Evidence that educational change can be fast indicates that the slow rate of reform in STEM instructional practices is likely a result, at least in part, of ineffective change strategies and models rather than the inherent difficulties of change. The change is slow argument is also problematic in that it encourages a passive attitude. Change in STEM instructional practices has been difficult and much slower than we would like. But, we should not use this as an excuse to avoid critically evaluating our current change strategies and models and seeking to improve them. Insanity has been defined as “doing the same thing, over and over again, but expecting different results”.[1] It is not clear why one should expect the development and dissemination model to work now when it has so far failed to yield the desired results.

We find it ironic that STEM reformers who chastise more traditional STEM faculty for not treating their teaching “scientifically” (see, for example, Ref. 1) will, in turn, not take a scientific approach to their reform efforts. As part of the interdisciplinary literature review mentioned earlier we examined claims of success or failure of the change strategy investigated [22]. Most of these articles (67%) claimed that the strategy studied was successful and few (12%) claimed that the strategy studied was not successful. We found that only 21% of the articles presenting strong evidence to support their claims of success or failure. An additional 28% presented adequate evidence, 39% presented poor

[1] This quote has been attributed to Albert Einstein, but more likely originated from Rita Mae Brown http://en.wikiquote.org/wiki/Rita_Mae_Brown.

evidence, and 12% presented no evidence. These results suggest that the standards for publishing research about educational change efforts in peer reviewed journals are not particularly high.

This low percentage of the articles in the literature review by STEM change agents that carefully document the impact of the change efforts is also particularly striking given that most STEM reformers do not even write articles about their change efforts. The articles that STEM reformers most often publish are typically designed to describe and disseminate information about a new instructional strategy. The many articles like this did not meet the inclusion criteria of the literature review (i.e., they did not explicitly discuss change models or strategies). Had they been included, the percentage of articles that were judged to not present evidence of success or failure of a change strategy would almost certainly be much higher.

Research secondary implementations

Research-based instructional strategies are often developed in one setting by a few individuals and then disseminated as if it will be easy for others in a different setting to incorporate them. The uniqueness of students, instructors and structures at each location make secondary implementations non-trivial. It is common for curriculum to be produced and disseminated that has not been tested in contexts beyond the environment in which it was developed. Most research-based curricula has been developed at research universities or elite liberal arts colleges. Conventional wisdom and available evidence suggest that these curricula do not always transfer directly to other environments [39-43]. For example, a ten-year study of the secondary implementation of the instructional strategy of Interactive Lecture Demonstrations found that student learning gains were “nowhere near” those claimed by the developers [42]. In order for dissemination to be successful we suggest that curriculum development efforts test and refine curriculum in environments fundamentally different from the development site; make explicit what aspects of the curriculum will transfer and under what conditions the transfer will be successful; make recommendations for modifications in different contexts, for example, how the curriculum could be modified for different sized classes, or for schools with less prepared students; and articulate why some aspects transfer better than others to guide instructors in their modifications. Understanding the whys behind transfer issues is also essential for building a general model to guide future development projects.

Develop tools and encourage policy to measure teaching based on student learning goals

One likely reason that instructional improvement has had such slow uptake is that neither faculty nor their institutions have many good tools to use to measure their effectiveness. For example, in follow-up interviews to our web survey of physics faculty, we asked faculty how they knew their teaching was working [7,8]. Many acknowledged they really did not have a good way of measuring their effectiveness. Others gave very vague answers indicating they had a general sense of it from interactions with students. Rarely did anyone have any objective measure to guide them. Further, when we asked how their teaching was evaluated by their institution, the answer was nearly always through student opinion. Overwhelming, faculty indicated that they felt student evaluations were not a particularly effective way of measuring teaching quality. The political ramifications of basing job performance evaluations on a measure that is not trusted by all parties aside, we believe the lack of more appropriate measures significantly impedes reform. If neither instructors nor their employers are able to assess effectiveness then there is no feedback mechanism to encourage and support reforms which improve student learning. We are not advocating the high stakes brand of testing that has come to dominate K-12 education. Our studies consistently indicate that both faculty and the departments they work in have a genuine and strong interest in improving student outcomes. Simply having clear feedback about what is working or not working is likely to go a long way toward encouraging research-based reform.

Conclusions

Implementing research-based reform on a large scale in STEM is not an easy task. Despite the intense efforts of change agents in developing and disseminating curricular products and ideas, progress has been slow. However, it is also the case that little effort has been put into developing an understanding of the basic problems and solutions of reform. Remedying this shortcoming offers many promising avenues for success.

Most of the money spent on the improvement of STEM education has been spent on research and development. Little effort has gone into understanding and improving the integration of the outcomes of that intense R&D effort in classrooms. Research into how students learn, along with the development of curriculum based on that research, is an essential component of reform. However, while there is still a need for more R&D effort in STEM, we now have a reasonably good understanding of what students need in order to learn, as well as a large collection of research-based curriculum and pedagogies. These research-based products, however, are being underutilized due to a lack of effort focused on understanding the problems and solutions of reform.

Fortunately, there is a clear, if somewhat challenging, solution. We, as a community, can improve our change efforts by remembering that successful change requires a successful change model. We can develop effective pedagogies and materials, but simply showing that these products are effective, and making them available, does not mean they will be used. Ultimately, researchers in STEM education, need to greatly increase efforts to understand change so as to develop more effective change models, and within those models more effective change strategies. **It is the systemic study and exploration of the reform process that offers the greatest promise for effective large-scale research-based reform.**

The current state of research on STEM *change* strategies is similar to the state of research on STEM *instructional* strategies 20-30 years ago. At that time STEM educational researchers started to systematically study teaching and learning. This has been tremendously effective in developing new knowledge and also in incorporating knowledge from other fields (e.g., psychology, sociology). We believe that research on STEM change strategies can be equally fruitful with more systematic research efforts.

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