Barriers and Promises in STEM Reform

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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 related to the improvement of STEM instruction. For example, since its creation in 1950, the Directorate for Education and Human Resources of the National Science Foundation (NSF) alone has directed over $22 billion toward the improvement of STEM education.[1]

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 (e.g., Handelsman et al., 2004). However, although substantial time and money has gone into developing and disseminating research-based pedagogy and curriculum, the limited evidence available suggests that these reform efforts are having only a marginal impact. For example, as the rationale for its 2003 report, the Committee on Undergraduate Science Education points to the strong research base on effective teaching approaches and then questions "why introductory science courses in many colleges and universities still rely primarily on lectures and recipe-based laboratory sessions where students memorize facts and concepts, but have little opportunity for reflection, discussion, or testing of ideas?" (National Research Council, 2003, p. 1)

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. The paper is organized around two large barriers to reform.

Barrier 1: STEM change strategies are primarily based on a development and dissemination change model.

Barrier 2: There is little research effort devoted to the study and improvement of STEM change strategies or models.

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[1] In constant FY2005 Dollars. Data provided by NSF: http://www.nsf.gov/about/budget/fy2007/tables/NSFSUMMARYTABLESCHARTS/ST-14.xls, Accessed 9-12-08.

Barrier 1: STEM Change Strategies are Primarily Based on a Development and Dissemination Change Model

Although there are a wide variety of change agents with a wide variety of expectations, most change agents within the STEM disciplines follow a development and dissemination change model.[2] This orientation of change agents 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 (Foertsch, Millar, Squire, & Gunter, 1997; Hutchinson & Huberman, 1994; National Research Council, 2003; Van Driel, Verloop, Van Werven, & Dekkers, 1997; Winter, Lemons, Bookman, & Hoese, 2001). As an example, consider the model of curriculum development and dissemination described in the 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." (National Science Foundation, 2008)

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.

Although it may be intuitively sensible, we have identified two negative manifestations of this change model that appear to impede its success at promoting productive change.

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[2] We use the term change *model* to indicate a coherent set of ideas about change. A Change *strategy* is a set of actions designed to bring about change, which may or may not be connected to a change model.

Manifestation 1a: Us vs. Them Mentality

One manifestation of this development and dissemination model is an us vs. them mentality where change agents and other faculty find themselves in opposition to one-another.

Change Agents Blame Faculty for Problems

Change agents are often surprised that faculty would choose not to use their well-developed and tested instructional strategy. Based on the development and dissemination model, if an instructional strategy has been proven to be effective, but is not used by faculty then it must be the fault of the faculty. Thus, change agents often view the major barriers to reform as coming from one or all of the following: 1) faculty believe that their current instruction is effective and see no reason to change, 2) faculty do not know much about the reforms, or 3) faculty are not willing to invest time to improve their teaching. There is very little or no evidence to support these views as the major barriers to reform. Each is discussed below.

Myth #1 - Faculty use traditional methods because they believe traditional methods are effective.

It is common for faculty development workshops to begin by presenting faculty with data showing that traditional methods are ineffective and that reform methods can lead to better results. The assumption is that a barrier to reform is that faculty are not aware of the problems with traditional instruction, or perhaps that they are somewhat aware but need more convincing. While it may be true that some faculty fall into this category, available evidence suggests that a large portion of faculty recognize many of the same problems with traditional instruction as documented in the research literature (Henderson & Dancy, 2007; Yerushalmi, Henderson, Heller, Heller, & Kuo, 2007). In addition, research has shown that there is not a clear one-to-one match between an instructor's beliefs about effective instruction and their actual instructional practices (Henderson & Dancy, 2008; Murray & Macdonald, 1997; Norton, Richardson, Hartley, Newstead, & Mayes, 2005; Yerushalmi et al., 2007). The evidence indicates that even when faculty are aware of, and agree with, the problems with lecture based teaching they often continue to use this method.

Myth #2 – Faculty use traditional methods because they are unaware of research based reforms.

The major thrust of most dissemination efforts is to make faculty aware of alternatives to traditional instruction. While it may be essential that faculty are aware of these alternatives if they are to reform their instruction, even when faculty have this awareness, our research suggests that they often fail to make use of this knowledge (Henderson & Dancy, 2008). There are other examples that indicate that the level of faculty awareness of research-based instructional strategies is much higher than their level of use of these strategies (Henderson, 2008; Walczyk & Ramsey, 2003). Thus, lack of awareness does not appear to explain the slow rate of research based reform in STEM.

Myth #3 – Faculty are mostly interested in research and are not willing to spend time improving their teaching.

Another common critique is that faculty are just too busy or too research oriented to care about implementing reforms. While it is true that some faculty fail to implement reforms because they simply

do not want to exert the effort, we believe that most faculty take their teaching responsibilities quite seriously and are willing to put effort into making improvements. Evidence of this willingness to put time into teaching can be seen by the attendance of faculty at professional development workshops. For example, from 1991 to 1997 the NSF's Undergraduate Faculty Enhancement (UFE) program funded teaching-focused professional development workshops for STEM faculty. These workshops were typically held during the summer and lasted from 3 to 10 days. Over 14,000 STEM faculty attended at least one workshop (Marder, McCullough, & Perakis, 2001). This represented approximately 1 in 22 STEM faculty in the United States (Marder et al., 2001). Similarly, approximately 25% of all new physics and astronomy faculty in the United States have attended the four-day Physics and Astronomy New Faculty Workshop which is heavily focused on teaching innovations (Henderson, 2008). In addition, Boice (1991) found that most new faculty, regardless of the type of institution, spend the majority of their time working to improve their teaching. Rather than working to implement research-based reforms, though, these faculty more commonly work to perfect their fact-based lectures (Boice, 1991). Thus, it appears that many dedicated and caring faculty also fail to implement research-based reforms (Henderson & Dancy, 2008).

The development and dissemination model of change tends to result in change agents placing the blame for a lack of change on faculty. In response, change agents then seek harder to try and get the word out to faculty and convince faculty of the importance of their teaching innovation. It is likely a necessary condition for change that faculty understand the need for change and have knowledge about alternatives. However, efforts by change agents to repeatedly inform faculty, driven by the assumption that faculty are the problem and that the solution involves getting faculty to come around, appears to exacerbate the problem.

Faculty Blame Change Agents

As discussed above, typical change agent efforts focus on the development and dissemination of new instructional strategies for faculty to implement more or less as is. Based on in-depth interviews with five physics faculty, our research suggests that this is not how faculty prefer to interact with reformers (Henderson & Dancy, 2008). The instructors we interviewed generally agreed with education research on the nature of the problems and the general idea of the solutions, but did not take the complete research-based solutions and implement them. When they used the research-based ideas at all, they developed or substantially changed the principles and details of these ideas.

Faculty appear to want different things from the research community than they perceive the community as currently offering. Below, we describe three categories that emerged from our interviews related to the interactions between researchers and the instructors.

Category I. Education Research is Perceived as Dogmatic

The interviewed faculty tended to see educational researchers as not really interested in them or their students, but rather as promoting a particular curriculum. Instructors described what they saw as the sales or evangelist mentality as making their interactions somewhat confrontational. Instructors also

criticized researchers as promoting their instructional package or technique with the expectation that it will work well in any environment, even ones quite different from the one in which it was developed.

Category II: Perception that Educational Research Says I'm a Bad Teacher

The research community has put much effort into discrediting traditional transmissionist instructional approaches. It is not unusual for researchers to report studies where research-based innovations are compared to more traditional lecture-based approaches with the innovation being shown to be superior. Although it is likely necessary for faculty to become dissatisfied with the traditional approach to teaching before they will consider alternatives, evidence from our interviews as well as other studies (e.g., Yerushalmi et al., 2007) suggest that this dissatisfaction already exists for many faculty. Although it is important to emphasize differences between research-based practices and traditional instruction, it appears this approach can be problematic if done without consideration for the emotional reactions that can be engendered.

The faculty we interviewed described emotional reactions to the message of educational researchers. These instructors saw educational researchers as insinuating that they are bad teachers. These faculty care about their students and have done their best with the knowledge they possessed and under the circumstances they found themselves. An important part of their identity is their role as an expert teacher. It is difficult when they perceive that the research community is telling them that they've been doing it all wrong and perhaps even causing harm to their students. Not unexpectedly, their reaction can be defensive.

Category III: Faculty Want to Be Part of the Solution

As a result of the way that these faculty perceive their interactions with educational researchers and the research results themselves, they tend to not make full use of research-based findings. They recognize that research has some good things to offer them and that researchers have expertise in teaching and learning that could be valuable. Yet, they feel a need to be part of the solution themselves. As one of the instructors put it, *"I've spent my life doing this [teaching] and part of my teaching is in fact to be aware of all of the things that are going on [in educational research], but I want it to be useful and meaningful to that discourse."* (Henderson & Dancy, 2008, p. 87)

The instructors we interviewed described the instructors' personal style, preferences, and skills as being very important in determining appropriate teaching practices. They did not expect any instructional package created elsewhere to work well for them with minimal or no modifications. This perceived importance of personal and local variables explains why they do not simply adopt an innovation as is even in cases when they believed in the usefulness of the innovation. What most of the instructors seem to describe as a desirable situation is some degree of collaboration where a change agent will work with them to decide on instructional practices that fit their individual situations. The instructional methods resulting from this collaboration would be based on the instructors' knowledge, skills, preferences, and teaching situation as well as on the available research knowledge about teaching and learning.

Solution 1a: Faculty Must Have a Meaningful Role in the Change Process

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 categories of change that vary in terms of the roles of the external change agent and the instructor in the change process (Fig. 1). These categories are not discrete, but occur on a continuum. We have found it useful, however, to use these categories to represent locations along the continuum. Notably, the responsibilities of the change agent and instructor change significantly across the continuum. At the adoption pole the change agent develops all of the materials and procedures and makes them available to the instructor to implement as is. In its extreme, this pole represents a change agent view that the instructor is irrelevant. At the invention pole the instructor develops everything with minimal external influence. In its extreme, this pole represents an instructor view that educational research is irrelevant. Under adaptation and reinvention, the general idea for a new instructional strategy comes from an external source, but the instructor is responsible for developing important aspects of the strategy. Although it is possible for an instructor to develop these aspects of the strategy with the assistance of a change agent, typically instructors develop these aspects of the strategy on their own. These instructor-developed principles and details are not always consistent with "best practices" as identified in the educational research literature (Henderson, 2005, 2008). For example, Henderson (2008) conducted web-based surveys of 527 physics faculty who had participated in the Physics and Astronomy New Faculty Workshop. Of these, 192 said that they used the research-based instructional strategy of Peer Instruction (Mazur, 1997). However, when asked to report on their actual instructional activities, only 19% of the 192 faculty reported instructional activities that *could* be consistent with the basic features of Peer Instruction as described by its developer.

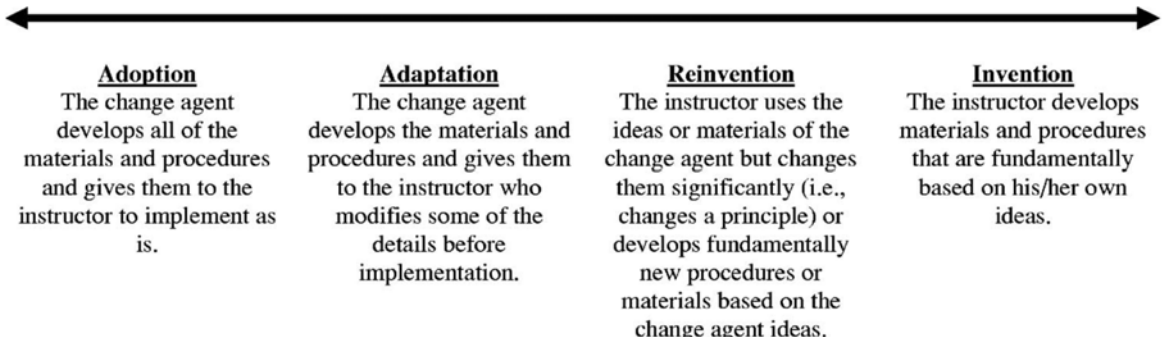

Figure 1: Adoption-Invention Continuum (Henderson & Dancy, 2008, p. 81).

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 appears that most faculty have a strong feeling of ownership over their teaching that makes

this division of labor unproductive. 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. One example is a project recently undertaken by Andy Elby and the University of Maryland Physics Education Research Group that encourages and supports customization through easily edited materials along with explanations about the instructional design and annotated video snippets of the materials and techniques in actual classroom use (McCaskey, Hodges, & Elby, 2005).

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 (Mazur, 1997) and may 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, 2003, p. 39) and tend to drop the peer-peer interaction part of Peer Instruction (Henderson & Dancy, 2005). 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. *Explicitly research the conditions for transfer.* It is not uncommon 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 (Sabella & Bowen, 2003; Saul & Redish, 1997). 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.

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 (Dancy, Brewe, & Henderson, 2007). 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 (Hestenes, 2000).

Manifestation 1b: Neglecting the Importance of Situational Factors

Another negative manifestation of the development and dissemination change model is that it obscures barriers that lie outside of individuals. Although change agents are often aware of strong situational conditions that favor traditional instruction, they often fail to document these barriers, mention the barriers in their dissemination efforts, or provide tools to help overcome the situational barriers. Because the development and dissemination change model focuses on change at the individual level, it encourages the neglect of situational factors and can lead change agents to blame other faculty for failure to be innovative: “I did it, why can’t you?”

Based on an analysis of interviews we found a disconnect between faculty instructional practices and their instructional conceptions, with conceptions being much more reform oriented than actual practice (Henderson & Dancy, 2007). For example, although all interviewees believed students learn more when engaged interactively, their actual practice was often lecture based with little opportunities for student interaction.

When conducting the analysis of instructor practices and conceptions as part of the above study, we noticed that instructors were often aware of inconsistencies between their conceptions (e.g. students learn best when allowed to develop ideas for themselves) and self-reported practice (e.g. lectures where the instructor develops ideas for the students). They generally attribute these inconsistencies to situational constraints and barriers.

Thus, we examined each interview to identify self-described situational factors that influenced an instructor's choice of either traditional or alternative practices. We found that most of the situational factors were described in terms of constraints preventing use of alternative instructional strategies.

A summary of the most salient barriers identified by our interviewees is given below.

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 be 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.

Solution 1b: Change Strategies Must Address the Strong Situational Conditions that Favor Traditional Instruction

These results indicate 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 situational barriers to instructional innovations.

We propose a model to describe how individual and situational characteristics relate to instructional practices (Figure 2). 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.

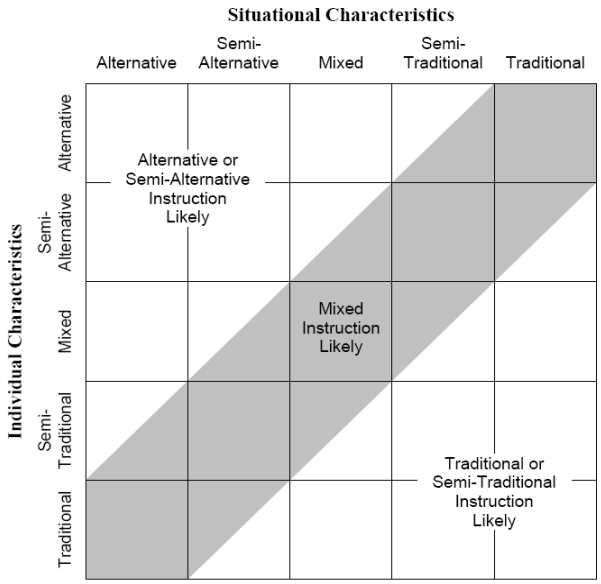

Figure 2: Model for predicting behavior based on individual and situational characteristics (Henderson & Dancy, 2007, p. 10).

Other studies of college science faculty (Prosser & Trigwell, 1999; Sunal et al., 2001) and non-science faculty (Murray & Macdonald, 1997; Norton et al., 2005) 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. It appears that this is a significant shortcoming of this 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. 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. After all, getting the chairs unbolted is often a nontrivial task.

Barrier 2: There is Little Research Effort Devoted to the Study and Improvement of STEM Change Strategies or Models

There is a lack of research on the study and improvement of change strategies in STEM. We believe that this shortcoming has enabled the unsuccessful development and dissemination model of reform to remain mostly unchallenged as the implicit or explicit model behind STEM change strategies for so long despite its poor record of 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".[3] 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.

Much of the data in this section comes from the preliminary results of an interdisciplinary literature review of change strategies used in college-level STEM reform (Henderson, Beach, Finkelstein, & Larson, 2008). The literature review included journal articles that describe efforts by change agents[4] to improve instructional practices used in undergraduate STEM education as well as articles focused on the

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

[4] By using the phrase "efforts by change agents," the intent was to exclude all articles related to descriptions of new teaching ideas developed by instructors with no emphasis on the dissemination of these ideas. There has been much work published in this area and descriptions of "best practices" are widely available. The goal of the literature review was to determine, in part, how this work can be used to impact teaching practices beyond the developers.

development of strategies or models relevant to such improvement efforts. Article selection was based on key word searches on Web of Science and ERIC for articles published between 1995 and February 2008. Abstracts were used to exclude articles that did not meet the content criteria. The final database contained 295 journal articles. The preliminary review is based on an analysis of 130 randomly chosen articles from the set. In the first round of analysis, an inductive process was used to identify two guiding questions that, when combined, form four categories of change strategies. The 130 articles were then re-reviewed and placed within the categories developed. In a second analysis round, 43 articles (initially evenly divided between the four categories) were selected for further examination. This included the formation of subcategories, an evaluation of the degree to which authors connected their work to other change literature, and the evidence authors presented to support the effectiveness (or lack thereof) of the change strategy.

The unquestioning acceptance of the development and dissemination change model has at least two manifestations that impede the improvement of change theories, and, thus, impede meaningful change.

Manifestation 2a: STEM Change Agents Frequently do not Study or Document the Impact of their Change Efforts

We find it ironic that STEM reformers who chastise more traditional STEM faculty for not treating their teaching "scientifically" will, in turn, not take a scientific approach to their reform efforts. As part of the interdisciplinary literature review, 12 of the 43 articles that we studied in depth had at least one STEM author.[5] Of the 12 articles analyzed, 5 did not present a specific change strategy about which one would expect to see evidence of success. Of the remaining 7 articles 5 (5/7 = 71%) were judged as not providing at least moderate evidence in support of the success or failure of the change strategy studied. Articles in this grouping typically limited their evidence to anecdotal accounts and/or very vague data sources. Note that this is not a particular failure of STEM reformers. Articles without STEM authors were also frequently (13/23 = 57%) judged as not providing at least moderate evidence in support of the success or failure of the change strategy used.

This low percentage of the articles in the literature review by STEM change agents that carefully document the impact of the change efforts is particularly striking given that most STEM reformers do not even write 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 be much higher.

Solution 2a: STEM Change Agents Should Seek to Document the Success (or Failure) of their Change Strategies

Change agents should seek to document the success of their change strategies. This is the only way that we can build a knowledge base.

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5 Authors were classified based on their departmental (or similar) affiliations. A STEM author is an author with an appointment in a STEM department or as a STEM education specialist in a college of education.

Research journals should not accept papers about change efforts without some evidence related to the impact of these efforts. (Just as research journals should not and do not generally accept papers about instructional innovations without some evidence related to the impact of the innovation, often in terms of improved student learning.)

Manifestation 2b: STEM Change Agents Rarely Connect Their Change Theories and Strategies to Other Change Strategies and Theories with STEM or to Change Strategies and Theories from other Disciplines

In addition to providing evidence to support assertions and decision making, another feature of "scientific" endeavors is that new knowledge is built on the foundation of current knowledge. This is not happening with respect to change strategies and theories, either within the STEM disciplines or in the wider higher education community.

Lack of coherent models of change grounded in research.

Fewer than half (5/12 = 42%) of the 12 articles with at least one STEM author cited literature that could be labeled as "change literature" despite a very inclusive definition of "change literature". Those that did not fit within our assessment of using change literature typically not only failed to ground their selected change strategy in the change literature, but also failed to justify their choice of change strategy in any way. Again, this is not a particular failure of STEM reformers. Of the articles without STEM authors, a similar percentage, (16/31 = 52%) were judged as making some connection to other change literature.

Minimal cross-field Communication

The literature review was begun with the assumption that at least three distinct research communities are involved in the improvement of undergraduate instruction in STEM disciplines. *Disciplinary-based STEM Education Researchers* (SER) are typically situated in STEM-related departments, frequently in a college of arts and sciences, but sometimes in a college of engineering or as disciplinary STEM specialists in a college of education. SER researchers are particularly interested in studying student learning within their discipline and developing discipline-specific curricular materials to improve this learning. *Faculty Development Researchers* (FDR) are typically situated in centers for teaching and learning. The mission of these centers is commonly to provide professional development for all faculty at an institution. Therefore, FDR researchers often focus on providing faculty with more general pedagogical skills or motivation and tools for self-improvement. *Higher Education Researchers* (HER) are typically situated in departments of educational leadership in a college of education and, sometimes, in university administration. HER researchers often study how cultural norms, organizational structures, and state and national environments and policy influence higher education practices. In contrast to the other groups, HER frequently focus their research beyond individuals to the institutional or national level. In addition to unique disciplinary interests and histories, each of these groups has its own distinct professional societies, journals, and disciplinary norms.

As expected, the analysis of the disciplinary backgrounds of authors of the 130 articles indicates that the three different disciplines (SER, FDR, and HER) included in the review each operate more or less independently of one-another and that each has their own distinct perspectives and strategies related

to change. HER authors tend to describe change strategies that focus on changing environments and structures rather than focus directly on changing individuals. In contrast, both SER and FDR primarily focus on changing individuals. As one might expect, SER authors tend to write about discipline-specific activities and most frequently focus on disseminating best practices. In contrast, FDR authors tend to focus on more general aspects of instructional improvement and are most frequently focus on developing reflective teachers and modifying instructor conceptions.

Solution 2b: STEM Change Agents Must Explicitly Link their Change Strategies to Other Change Strategies or Models and to Learn About and Incorporate Change Strategies and Models from Other Disciplines

STEM change agents need to learn from one-another as well as from other fields. As a preliminary result of the literature review Henderson et. al. (2008) identified four core categories of change strategies that have been used in undergraduate STEM (Table 1).

Table I: *Overview of Four Change Categories with Subcategories* (adapted from Henderson et. al. (2008), p. 19.).

<table>
<tr><td></td><td colspan="2">Aspect of System to Be changed: Individuals</td><td></td></tr>
<tr><td rowspan="2">Intended Outcome: Prescribed</td><td>I. Disseminating: CURRICULUM & PEDAGOGY
(38% of all articles, 56% of articles with at least one STEM author)

Subcategories:
1) Disseminate Best Practices (7 articles).
2) Modify Instructor Conceptions (4 articles).
3) Provide Individualized Diagnosis and Support (1 article).</td><td>II. Developing: REFLECTIVE TEACHERS
(39% of all articles, 37% of articles with at least one STEM author)

Subcategories:
1) Individual Curriculum Development (4 articles).
2) Collaborative Action Research (3 articles).
3) Provide information to help faculty make informed decisions (3 articles).
4) Departmentally-Based Faculty Development Specialists (1 article).</td><td rowspan="2">Intended Outcome: Emergent</td></tr>
<tr><td>III. Developing: POLICY
(18% of all articles, 4% of articles with at least one STEM author)

Subcategories:
1. System Synchronicity (6 articles).
2. Institutionalization of quality assurance measures (4 articles).
3. Directed Incentives (3 articles).</td><td>IV. Developing: SHARED VISION
(6% of all articles, 4% of articles with at least one STEM author)

Subcategories:
1. Institutional-Level Actions (3 articles).
2. Externally initiated department level collaboration (2 articles).
3. Internally initiated department level collaboration (1 article).</td></tr>
<tr><td></td><td colspan="2">Aspect of System to Be changed: Environments and Structures</td><td></td></tr>
</table>

The four categories of change strategies are based on the answers to two fundamental questions. 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 address such factors as the beliefs and behaviors of instructors, assuming that they act of their own

volition. Moving beyond individuals to environments and structures, the change strategy seeks to impact the environments that are assumed to influence the actions of individuals.

The second fundamental guiding 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(s) have 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 one (Disseminating Curriculum and Pedagogy). These other categories of change strategies can address the weaknesses associated with the focus on development and dissemination identified in the first part of this paper. Namely, that intended outcomes should not be completely prescribed in advance and that environments and structures (in addition to individuals) need to be focused on in change strategies.

Conclusion

Implementing research-based reform on a large scale in STEM is not an easy task as evidenced by the slow progress despite the intense efforts of change agents such as those represented in the workshop for which this paper was prepared. However, analysis of the situation offers many promising avenues for success. All of the findings we report in this paper and all of our recommendations essentially point in the same direction: little effort has been put into developing an understanding of the basic problems and solutions of reform.

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 dissemination 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. The development and dissemination model of change, dominating our reform efforts, has not been successful. No matter how strongly our intuition tells us that it should work, evidence of repeated failed reforms using this model indicates that it needs to be greatly refined if not discarded. 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.

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