Beyond Dissemination in College Science Teaching: An Introduction to Four Core Change Strategies

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Within the science, technology, engineering, and mathematics (STEM) education community there are repeated calls for the reform of undergraduate teaching. Resulting change efforts often focus on developing and disseminating specific instructional ideas and practices to individual faculty. However, in this paper we argue that these efforts need to be expanded to include more emphasis on faculty involvement in the change process, as well as on the environments and structures within which faculty work. We present four core change strategies that frame a broad span of considerations for enacting and sustaining new educational programs: (1) disseminating curriculum and pedagogy, (2) developing reflective teachers, (3) developing policy, and (4) developing shared vision. These strategies emerged from an interdisciplinary literature review of hundreds of articles in faculty development, STEM education research, and studies of higher education.

Over the last several decades, there have been many calls for the reform of undergraduate science, technology, engineering, and mathematics (STEM) courses, based on extensive research demonstrating the significant limitations of traditional lecture-based instruction. Substantial 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 a considerable amount of time and money have gone into developing and disseminating research-based pedagogy and curricula, available evidence has suggested that these reform efforts are having only a marginal impact. For example, the National Research Council 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" (NRC 2003, p. 1).

We engaged in an interdisciplinary literature review in order to better understand what change strategies are used to impact undergraduate STEM instruction. The 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 (SERs) 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. Faculty development researchers (FDRs) are typically situated in centers for teaching and learning. Higher education researchers (HERs) are typically situated in departments of educational leadership (or similar) in a college of education and, sometimes, in university administration.

An important finding from the literature review, based on an analysis of the disciplinary backgrounds of authors, is that that the three disciplines (SER, FDR, and HER) each operate more or less independently of one another, and each has its own distinct perspectives and strategies related to change. HER authors tend to describe change strategies that focus on changing environments and structures rather than those that focus directly on changing individual faculty. In contrast, both SERs and FDRs primarily focus on changing individual faculty. As one might expect, SER authors tend to write about

discipline-specific activities and most frequently focus on disseminating specific instructional strategies. In contrast, FDR authors tend to focus on more general aspects of instructional improvement and most frequently focus on helping faculty become more reflective about their teaching or develop conceptions of teaching that are student centered.

Because of the diversity of perspectives and relative isolation of these research communities, it seems that each community has the opportunity to improve change efforts by learning about the perspectives of the other communities. In the remainder of this article, we briefly identify some of the weaknesses of the development-and-dissemination change strategy common within the SER community. We then describe four core categories of change strategies that emerged from the literature review, arguing that we should broaden our approaches to development and dissemination to include perspectives from other change strategies.

Problems with development and dissemination

In the SER community, the dominant approach to change is that of development and dissemination. We believe this approach has persisted in the SER community for so long, despite a lack of proven success, because it makes intuitive sense. Conducting education research and developing new curricular materials requires considerable time and expertise that STEM faculty typically does not possess. Therefore the development task is delegated to a small number of individuals, and the "finished products" are given to other faculty for implementation. The assumption is that the faculty will be convinced to use these new instruc-

tional materials and strategies once they are shown data demonstrating improved student learning.

Although it may be intuitively sensible, there are two basic problems with the dissemination approach: (1) There is no meaningful role for typical faculty to play in the change process, and (2) it does not address the environments and structures that faculty work within, which typically favor traditional instruction. This approach assumes that the curricular innovations are static and independent of both environment and instructor (i.e., are teacher and environment proof). Many faculty react negatively to the lack of ownership that is allowed them under development and dissemination. On the basis of in-depth interviews, Henderson and Dancy (2008) found that although physics faculty generally agreed with education research on the nature of instructional problems and the general idea of proposed solutions, they did not take the complete research-based solutions and implement them. The faculty recognized that research had some good things to offer them and that researchers have expertise in teaching and learning that could be

valuable. Yet, they felt a need to be part of the solution themselves. As one of the interviewees 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 education research], but I want it to be useful and meaningful to . . . discourse [about instructional changes]" (Henderson and Dancy 2008, p. 87).

Although reformers are often aware of environments and structures that favor traditional instruction, they often fail to document these barriers, mention the barriers in their dissemination efforts, or provide tools to help faculty overcome the barriers (Finkelstein and Pollock 2005). Common environmental features such as content-coverage expectations, lack of instructor time, departmental norms, student resistance, class size and room layout, and time structure can impede an instructor's ability to implement innovative instruction (Henderson and Dancy 2007).

Four categories of change strategies

Data presented here are preliminary results of an interdisciplinary litera-

ture review that identified four core change strategies (Henderson et al. 2008a, 2008b). The review included journal articles 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 (see *Note* at end of article). Article selection was based on keyword searches on Web of Science and ERIC for articles published between 1995 and 2008. The final database contained 295 journal articles. The preliminary review is based on an extensive analysis of 130 randomly chosen articles from the set.

The four categories of change strategies (Figure 1) are based on a multistage qualitative analysis. The inductive analysis process involved reading and initial coding of articles (by overlapping pairs of research team members) to identify the research community of the authors, the focus of the change approach, the "level" at which the change described is being aimed (individual, group, institutional, extra-institutional), the apparent role of the change agent if discernable, and the degree of specificity of the outcome intended. The research team then met several times in person and by phone conference to discuss what we had learned from our initial reading of the chosen articles, ways to define the patterns and themes we saw emerging from the articles, and how we saw those patterns coming together to form potentially useful categories. From these initial coding approaches emerged two fundamental questions that, when combined, form four categories of change strategies. We then reviewed the 130 articles and placed them within the categories developed.

The first fundamental coding 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 is determined as part of the change process, with the assumption that those involved in the change have important information needed to define the outcomes.

Of the 130 randomly chosen articles, 103 were categorized for the analysis presented here. We determined that 14 articles were not relevant to our analysis and removed them. Several were curriculum-development articles focused only on student learning outcomes (one of our exclusionary criteria); others were focused on K–12 education. Nine articles were classified "background" reading. They did not directly fit the search criteria, but are relevant in some way and are particularly well written or comprehensive. Four articles clearly spanned more than one category. All four of these were review articles that did not present and discuss specific change interventions but discussed a range of issues regarding instructional change.

The distribution of the remaining 103 articles can be found in Figure 1.

One of the main arguments in this paper is that, of the four categories of change strategies, SER change agents strongly favor the individual and prescriptive category (Disseminating Curriculum and Pedagogy). Of the 103 articles, 17 (17%) have only SER authors and 27 (26%) have at least one SER author. Figure 2 shows that the articles with SER authors were not evenly distributed throughout the four categories, but rather were clustered in the Disseminating Curriculum and Pedagogy category. For example, of the articles with only SER authors, 11 (65%) were categorized as Disseminating Curriculum and Pedagogy, 4 (24%) were categorized as Developing Reflective Teachers, 1 (6%) was categorized as Developing Policy, and 1 (6%) was categorized as Developing Shared Vision.

The other three categories also tend to be favored by one disciplinary group. The emergent individual category (Developing Reflective Teachers) is largely the purview of faculty developers where 63% of the articles have at least one FDR author. The prescribed environment category (Developing Policy) is dominated by higher education researchers where 72% of the articles have at least one HER author. Finally, the emergent environment category (Developing Shared Vision) is relatively unexplored in STEM education change, representing only 6% of the articles. Half of the articles have at least one HER author. Overall, there were very few articles that could not be easily classified within one of the four core change strategies. In the following sections, we will use several articles from the literature review to discuss the four categories of change strategies.

Disseminating curriculum and pedagogy

Change strategies in this category typically focus on teaching or training faculty on specific new instructional techniques or ways of thinking about teaching and learning. This is most commonly done through transmission-oriented workshops, presentations, and publications. Strong evidence supports the conclusion that this sort of information dissemination and training by itself, no matter how well done, is not highly effective (Fixsen et al. 2005). Dissemination, however, can be effective when it involves a more comprehensive and longer-term intervention, often involving such components as performance evaluation and coaching (Fixsen et al. 2005).

As an example of a disseminating curriculum and pedagogy change strategy, we consider work from Gallos, van den Berg, and Treagust (2005), which describes a relatively sophisticated approach to dissemination that combines initial training with coaching and monitoring during implementation. The authors described the implementation of a revised first-year general chemistry course to replace the traditional course, which consisted largely of passive lectures. The new course was pilot tested by two instructors in the department and revised. In the first stage of the change process, during the pilot testing, fourteen additional instructors in the department were exposed to the new instructional approach through observations of the new course in action. These instructors also participated in weekly training sessions. In the second stage of the change process, 13 of the 14 additional instructors implemented the new course in parallel sections. In small groups, the instructors met weekly with the course designer to discuss implementation problems. The entire group also met monthly to discuss the course. The course developer and two other colleagues regularly observed lessons and provided feedback and assistance to the instructors.

On the basis of a variety of data collected, including classroom observations and videotapes, the authors concluded that 3 of the 13 instructors were successful in implementing the new instructional style as intended, with clear minilectures, well-managed student seatwork, and a closure that included discussion of learning difficulties encountered during the seatwork phase. Six instructors were judged to be partially successful because they tended to return to lecture mode when difficulties arose, such as a conflict of views during discussion or students being off task. Four instructors were judged to be unsuccessful. The authors concluded that, with the support provided, 9 out of the 13 instructors were able to make significant changes in their instructional styles. Four instructors, however, were not able to make the change successfully because of a combination of weak content knowledge and weak classroom management skills. They noted that, although substantial changes were made during the project intervention, it was too early to say whether these changes would be sustained.

Although this project is an exemplar of change through development and dissemination of materials and prescriptive outcomes for individual faculty, it identifies the need to consider broader aspects of the system. The authors suggested that the changes may have been more successful if the implementing faculty had been more highly involved in the course development process (reflective teachers) and alluded to the structural and cultural barriers (policy and shared vision) that challenge the sustained success of their efforts.

Developing reflective teachers

Change strategies in the reflective teachers category typically focus on encouraging faculty to reflect on and improve their instruction. This is done in a variety of ways with some common approaches, including (1) individual consultation with a faculty devel-

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FIGURE 2

Overview of four categories of change strategies (adapted from Henderson et al. 2008b, p. 19). SER = STEM education researchers.
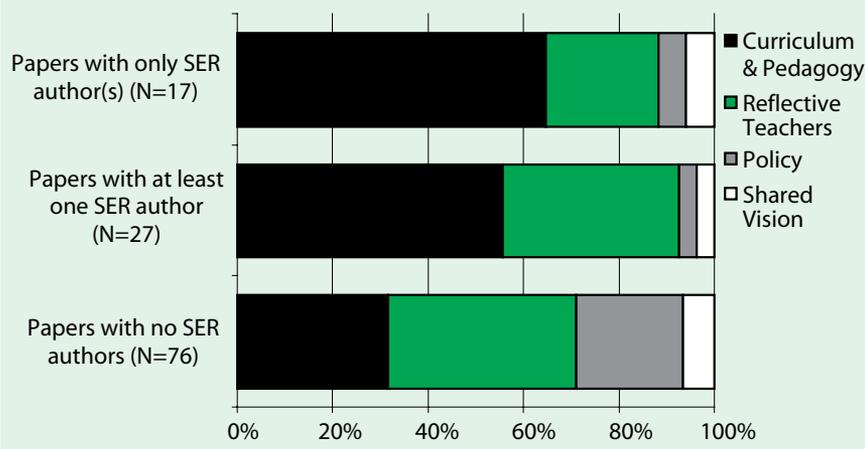
opment specialist (e.g., Piccinin, Cristi, and McCoy 1999); (2) providing faculty with a variety of resources about various instructional possibilities (e.g., Henderson 2008); (3) encouraging faculty to engage in data collection within their own classrooms, such as action research (e.g., Kember and McKay 1996) or scholarship of teaching and learning (e.g., Connolly, Bouwma-Gearhart, and Clifford 2007); and (4) encouraging small groups of faculty to collaborate on instructional improvement (e.g., Stevenson et al. 2005). An important feature of change strategies in this category is that the faculty member(s) being impacted have an important role to play by bringing their knowledge and experiences to the change process. This means that the role of the change agent is typically that of facilitating or encouraging individuals or groups to engage in reflective activity that leads to emergent instructional changes.

Krockover et al. (2002) provided an example of a change strategy in this category. The authors described an approach in which teams consisting of a scientist, a science educator, a K–12 teacher, a preservice teacher, and a graduate teaching assistant were created to work on the reform of three individual courses. The authors noted that one of the benefits of using a collaborative curriculum-development approach is that because the changes are established through a developmental process, they are well adapted to both the local environment as well as the personal style and strengths of the implementing instructor. The authors also identified disadvantages with this change strategy. One is that participating in this project required a substantial time commitment from faculty without a reduction in other responsibilities. They also noted that the scientists they worked with did not have the skills necessary to as-

sess instructional effectiveness, and therefore, it is crucial to have science educators involved.

Developing policy

Both of the previous change strategies focus on the individual, leaving the environments as fixed external entities. Change strategies in the developing policy category seek to influence faculty instructional behavior by making changes in the environments or structures within which these faculty work. These structural changes are often formal changes in policy, such as the requirement that faculty participate in a new accountability system (e.g., Wright, Knight, and Pomerleau 1999). However, the changes can also be informal ones that are likely to influence faculty behavior in a particular direction. For example, some approaches call for changes in the reward system at colleges and universities to reward teaching success more comparably to research success (Brand 1992). Notably, formal policy changes are, by themselves, not thought to be highly successful, because a common reaction of individuals in a wide variety of contexts is to appear to comply with the new requirements on paper without actually changing their behavior (Burke 2002; Honig and Hatch 2004; Spillane 2004). Often this is the result of change agents not understanding all aspects of the system that they are seeking to change (Colbeck 2002; Skoldberg 1991).

An example of a change strategy in this category is the work of Major and Palmer (2006), who studied the implementation of problem-based learning (PBL) at a private university. The three-year, grant-funded project involved integrating PBL across the undergraduate curriculum. PBL, as the authors noted, "dramatically al-

ters the roles of content, faculty, and student" (Major and Palmer 2006, p. 623). Participation was widespread during the intervention period; however, once the funding period ended and the institutional pressures were released, most faculty indicated that they would continue to use aspects of PBL that they believed to work well but did not plan to continue use of the entire system.

Developing shared vision

Change strategies in the developing shared vision category seek to influence groups of faculty (and, perhaps, other relevant stakeholders) to come together and develop a shared vision for instructional improvement and identify the environmental changes that are likely to lead to such improvement. This approach most commonly occurs at the departmental or institutional level and can be initiated by insiders or outsiders. 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 on the basis of distributed knowledge in a system and individual buy-in are consistent with recent trends in the organizational-change (Deetz, Tracy, and Simpson 2000) and business literature (Nonaka and Takeuchi 1995).

Kressel, Bailey, and Forman (1999) provided an example of a change strategy in this category that focuses on a department-level intervention involving an outside consultant working with individual departments to identify needs and then to develop and implement strategies that address those needs. Faculty decided, as a group, which issues to address and how to address them. In many cases the authors noted that the consultation process had not only led to productive instructional changes within the

department but also reduced conflict within the department. They also noted that the type of collaborative process they promoted is not typically a part of the culture of higher education, which places a premium on the autonomy of individual faculty.

Conclusions

Each of the four core change strategies has upsides and downsides. These are summarized in Table 1. Change agents should be aware of the downsides of their chosen change strategy and seek to mitigate these downsides by incorporating aspects of other strategies and, perhaps, working with change agents from one of the other two communities. In particular, SER change agents can address some of the weaknesses of commonly used dissemination curriculum and pedagogy change strategies by learning from FDR and HER change agents who more commonly operate within the other categories of change strategies. FDR change agents often operate within the developing reflective teachers category and know how to help faculty develop emergent instructional practices that are suited to their individual teaching situations and personal preferences/skills. HER change agents who operate within the developing policy category know how to shape environments and structures in a way that can lead faculty to make teaching improvements. Change agents who operate within the developing shared vision category know how to bring together groups of faculty and empower them to help shape their environments.

We hope that, in the short term, the proposed four core change strategies will help change agents reflect on and expand their work. This relatively simple framework can help elucidate areas of focus that all too often remain as tacit, immutable components of our educational system. As we engage in education transformation, this framework can help us locate our efforts and suggest avenues for further work. Ultimately, for the field to advance, there needs to be increased emphasis on the study, development, and testing of change strategy. We expect that successful change strategies will be built by collaborative teams of researchers

TABLE 1

Overview of upsides and downsides of each of the four categories of change strategies.

Category of change strategy	Upsides	Downsides
Disseminating Curriculum and Pedagogy	• Developing good curricula is beyond the skills and available time of most faculty. • Change agents are able to experimentally document the effectiveness of new curricula compared to alternatives.	• Faculty may use new curricula inappropriately or not at all. • Most effective curricula conflict with traditional environments.
Developing Reflective Teachers	• Faculty have ownership of the new curricula. • New curricula is customized to the instructor and teaching environment.	• Faculty-developed materials may not be as strong as those developed by educational researchers. • Traditional environments do not reward a focus on teaching.
Developing Policy	• Traditional environments are often barriers to change. • Can often be implemented relatively quickly.	• Faculty may subvert policy changes. • Loose coupling of university environments tends to complicate top-down efforts.
Developing Shared Vision	• Group norms are a key change lever and not easily changed by policy changes. • Incorporates specialized knowledge of stakeholders throughout the system.	• The new shared vision may not be in the direction desired by the change agent. • No clear guidance available for change agents. • Resource intensive

and will span multiple categories. It is only in working together, recognizing the broad array of individuals and structures and the varied approaches that may be taken, that change agents operating within these four categories are likely to make a significant impact on STEM instructional practices in higher education. ■

Note: 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 available elsewhere. The goal of the literature review was to determine, in part, how this work can be used to impact teaching practices beyond the developers.

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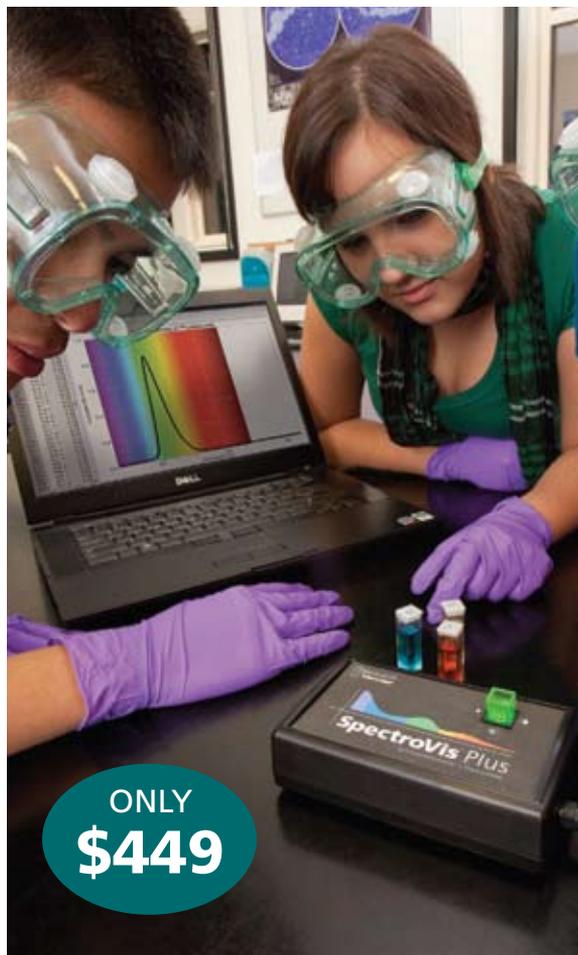Skoldberg, K. 1991. Strategic changes in Swedish higher education. *Higher Education* 21 (4): 551–572.

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Charles Henderson (charles.henderson @wmich.edu) *is an associate professor in the Department of Physics and the Mallinson Institute for Science Education at Western Michigan University in Kalamazoo, Michigan.* ***Noah Finkelstein*** *is an associate professor in the physics department at the University of Colorado at Boulder in Boulder, Colorado.* ***Andrea Beach*** *is an associate professor in the Department of Educational Leadership, Research, and Technology and the Director of Faculty Developmen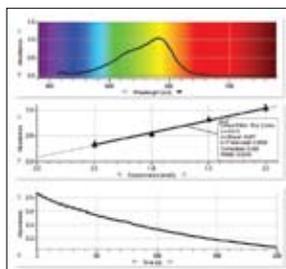t at Western Michigan University in Kalamazoo, Michigan.*