

Facilitating Change in Undergraduate STEM: Initial Results from an Interdisciplinary Literature Review

Charles Henderson*, Andrea Beach[†], Noah Finkelstein[§], R. Sam Larson[¥]

**Department of Physics, Western Michigan University, Kalamazoo, MI 49008, USA*

[†]*Department of Educational Leadership, Western Michigan University, Kalamazoo, MI 49008, USA*

[§]*Department of Physics, University of Colorado at Boulder, Boulder, CO 80309, USA*

[¥]*Integrated Quality Systems & Tools, Kaiser Permanente Colorado, Denver, CO 80237, USA*

Abstract. Although decades of research have identified effective instructional practices for improving Science, Technology, Engineering and Mathematics (STEM) education, these practices are not widely implemented. Scholars in three fields are interested in promoting these practices and have engaged in research on pedagogical change: Disciplinary-based STEM Education Researchers, Faculty Development Researchers, and Higher Education Researchers. There is little interaction between the fields and efforts in all areas have met with only modest success. In this paper we present an initial examination of 130 randomly chosen articles from a set of 295 we identified as addressing efforts to promote change in the instructional practices of STEM faculty. We identify four core change strategies and note that change strategies differ by fields. Articles in all fields frequently do not provide enough evidence to convincingly argue for the success of the change strategy studied and have few connections to theoretical or empirical literature related to change. This literature review and related efforts sit within broader efforts to promote interdisciplinary directed at facilitating lasting change.

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INTRODUCTION

Recent decades have seen increasing calls for fundamental change in the teaching of Science, Technology, Engineering, and Mathematics (STEM). National commissions, state panels, university administrators, and individual researchers have expressed concern that the United States will lose its role as a leader in science and technology fields due to outdated and inappropriate instructional practices [1]. These concerns have led to significant expenditures of time and money on research into improving teaching and learning. Yet, these efforts have met with only modest success [2].

We see three distinct research communities involved in this endeavor to improve undergraduate instruction in STEM disciplines. *Disciplinary-based STEM Education Researchers* (SER) are particularly interested in studying student learning within their discipline and developing discipline-specific curricular materials to improve this learning. *Physics Education Researchers* (PER) are a large and important sub-set of SER. *Faculty Development Researchers* (FDR) often focus on providing faculty with more general

pedagogical skills or motivation and tools for self-improvement. *Higher Education Researchers* (HER) often study how cultural norms, organizational structures, and state and national environments and policy influence higher education practices.

We see a need for interdisciplinary research on STEM instructional improvement that draws from the knowledge and experiences of all of these research communities. Therefore, this project seeks to move towards an integrated research agenda focused on STEM instructional improvement. The initial analysis of the peer-reviewed literature presented here is one of the early steps in this larger project. Although we realize that other sources of knowledge exist (and plan to include them at a later date), we intentionally chose journal articles as a starting point for our analysis because they are the most accessible by the broadest number of people and may greatly influence researchers and stakeholders in STEM education.

The research questions that guided this initial review of the literature are:

- 1) What strategies do change agents use to promote change in undergraduate STEM teaching practices?
- 2) How do change strategies described by authors relate to the disciplinary background of the authors?

3) What evidence is available to support the effectiveness of these strategies?

4) How do authors connect their work with other change literature (e.g., individual and organizational change theories)?

METHODS

For this review, we identified journal articles that describe efforts by change agents to improve instructional practices used in undergraduate STEM education.¹ Article selection was based on key word searches (e.g., “change”, “teaching”, “instruction”, “improvement”, “higher education”, “college”, and “university”) 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. We also examined particular journals that might contain relevant articles, as well as reference lists from selected articles. The final database contains 295 journal articles. For this initial review, we examined 130 randomly chosen articles from the set. We used an inductive analysis process that involved reading and initial coding of articles 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), and the degree of specificity of the outcome intended. From these initial coding approaches emerged two guiding questions that, when combined, form four categories of change strategies. We then re-reviewed the 130 articles and placed them within the categories developed.

In a second analysis round, we selected 10 articles from each of the four categories for further qualitative examination. We looked for meaningful subcategories of strategies, the degree to which authors ground their work in established change literature, and the evidence authors present to support the effectiveness (or lack thereof) of the change strategy. We consider the results presented below to be preliminary because they are based on an analysis of only 130/295 (44%) of articles in our database, of which only 43/295 (15%) were further analyzed for subcategories and themes. Additional details about the methodology and results can be found in Ref. [3].

¹ By using the phrase “efforts by change agents,” we intend 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. We wish to determine, in part, how this work can be used to impact teaching practices beyond the developers.

ANALYSIS AND RESULTS

The four proposed categories of change strategies are based on the answers to two fundamental questions that were arrived at through multiple rounds of initial coding and discussion. The first question was, “What is the primary aspect of the system that the change strategy seeks to directly impact?” We identified two discreet answers to this question – *individuals* (The change intends to directly impact personal characteristics of single individuals, such as beliefs, knowledge, behaviors, etc.) or *environments and structures* (The change intends to directly impact characteristics of the system that are external to single individuals, such as rules, physical characteristics of the environment (e.g., room layout, technology), norms, etc.). The second fundamental guiding question was, “To what extent is the intended outcome for the individual or environment known in advance?” We identified two responses we labeled *prescribed* (The desired final state for the individual or environment is known at the beginning of the change process) and *emergent* (The desired final state for the individual or environment is developed through the change process).

Four Categories of Change Strategies

Based on the possible combinations of responses to the two guiding questions, we developed a four-square typology of change strategies (Figure 1).

		Aspect changed: Individuals			
Intended Outcome: Prescribed	I. Disseminating: CURRICULA & PEDAGOGY	Tell/Teach individuals about new teaching conceptions and/or practices and encourage use.	II. Developing: REFLECTIVE TEACHERS	Encourage/Support individuals to develop new teaching conceptions and/or practices.	Intended Outcome: Emergent
	III. Developing: POLICY	Develop new environmental features that Require/Encourage new teaching conceptions and/or practices.	IV. Developing: SHARED VISION	Empower/Support stakeholders to collectively develop environmental features that support new teaching conceptions and/or practices.	
		Aspect changed: Environments and Structures			

FIGURE 1. Four-Square Typology of Change Categories

Of the 130 articles randomly chosen for initial analysis, we determined that 14 were not relevant to our analysis and removed them. Nine articles were classified as “background.” Four articles could not be

classified in a single category. All four of these were review articles that discussed a range of issues regarding instructional change. The remaining 111 articles fit into one of the four core categories described above. The next four sections describe in detail the four categories developed through initial coding and summarize roughly ten articles apiece that fall within each subcategory.

Individual/Prescribed: Focus on Disseminating Curriculum and Pedagogy. (39 articles, 30%). The emphasis of this type of intervention is on communicating the change agent's vision of good teaching to individual instructors. The prominent aspects of the interventions typically include curricular materials, instructional strategies, and/or associated instructor knowledge/conceptions. The following subcategories were identified:

1) Disseminate Best Practices (7 articles). Change agent seeks to disseminate (and, perhaps develop or compile) a set of "best practices" instructional strategies or materials.

2) Modify Instructor Conceptions (4 articles). Change agent seeks to promote adoption of a set of instructional conceptions that are "best practices."

3) Provide Individualized Diagnosis and Support (1 article). Change agent works with individual instructors to identify and improve instructional difficulties.

Individual/Emergent: Focus on Developing Reflective Teachers. (40 articles, 31%). The emphasis of this type of intervention is on encouraging teachers to use their own knowledge, experience, or skill to improve their instructional practices. Information about various instructional strategies and materials may be provided, but this is not the main focus. The following subcategories were identified:

1) Support for Individual Curriculum Development (4 articles). Individuals reflect on teaching and develop, test, and refine new instructional ideas.

2) Collaborative Action Research (3 articles). Teams of faculty (often from multiple disciplines) work together to develop, test, and refine aspects of a particular course.

3) Help Faculty Make Informed Decisions (3 articles). An external change agent introduces faculty to a wide set of new pedagogical ideas and encourages faculty to use their expertise to reflect on and adapt the ideas to their own teaching situations (there is no explicit action-reflection phase).

4) Departmentally-Based Faculty Development Specialists (1 article). A faculty member within a department is given release time to address local faculty development needs.

Environments/Prescribed: Focus on Developing Policy. (18 articles, 14%). The emphasis is on developing appropriate environments (e.g., rules,

reward systems, reporting requirements, investments in support structures) to facilitate instructors' engaging in specific or desired activities. The following subcategories were identified:

1) System Synchronicity (6 articles). Top-down change initiatives need to be consistent with key aspects of the system.

2) Institutionalization of Quality Assurance Measures (4 articles).

3) Directed Incentives (3 articles). Presidents, chairs, and deans can influence change by offering incentives or recognition.

Environments/Emergent: Focus on Developing Shared Vision. (6 articles, 5%). The emphasis is on developing a new collective vision for the department, institutional unit, or institution that supports new modes of instruction. The change agent uses instructor (and typically other) stakeholders to develop a shared vision and design new environments that are consistent with this vision.

Several articles that appeared upon initial review to address shared vision were found upon deeper scrutiny to address how culture serves as a barrier or a variable in policy implementation. Such articles were moved to the policy category. The following subcategories were identified:

1) Institutional-Level Actions (3 articles). Change agents work across entire institution.

2) Externally Initiated Department Collaboration (2 articles). Change agents work at the departmental level.

3) Internally Initiated Department Collaboration (1 article). Change in the department is initiated from within.

DISCUSSION AND CONCLUSIONS

1. Change Strategies Used. Change strategies described in the articles were much more likely to focus on changing individual faculty (61% of all 130 articles) than on changing environments or structures (19%). The articles were more evenly divided between working towards prescribed outcomes (44%) and emergent outcomes (36%). We conclude that change agents frequently work at the individual level, rather than at extra-individual levels. Although the number of articles published may not be a perfect proxy for the activities of change agents, we expect a high correlation between the two since we are dealing with academic communities who place a premium on publishing their work.

2. Use of Different Change Strategies by Different Disciplines. We proposed that the three different disciplines (SER, FDR, and HER) each operate more or less independently of one-another and

that each has their own distinct perspectives and strategies about change. The literature classification supports this proposition. Articles in the Policy and Shared Vision categories, which focus on changing environments and structures, were written primarily by HER authors, 68% and 50% respectively. In contrast, articles in the Curriculum and Reflective Teachers categories, which focus on changing individuals, were written primarily by SER and FDR authors, 69% and 65% respectively. SER authors tend to write about discipline-specific activities and are most frequently found in the Curriculum category, particularly subcategory 1 (Disseminate Best Practices). In contrast, FDR authors focus on more general aspects of instructional improvement and are found in the Reflective Teachers category and, to a lesser extent, in the Curriculum subcategory 2 (Modify Instructor Conceptions).

3. Evidence of Effectiveness of Change Strategies. Of the 43 articles analyzed, 13 did not present a specific change strategy warranting evidence of success. Of the 30 remaining, we judged 12 (40%) to have at least moderate evidence supporting their assertions of success (or lack thereof) of a change strategy. Five articles were judged to offer weak support, and 11 offered little or no evidence in support of their claims. No articles offered strong evidence supporting the success of a change intervention.

4. Connections with Other Change Literature. Fewer than half (20/43) of the articles cited literature that we could label “change literature.” We purposely left the definition of “change literature” very open. Our conception encompasses literature on topics such as reflection, action research, diffusion of innovation, organizational culture, policy, and theory, other social science theories, and empirical studies related to change. 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. This trend was consistent across the four change strategies.

CONCLUDING THOUGHTS

We plan to continue analyzing articles using a constant comparative approach, revising, expanding or shifting categories to best reflect the contents of the articles. An important trend thus far in the analysis is that it appears to be possible to use two relatively simple criteria to usefully categorize articles about STEM instructional change into a small number of meaningful categories. There were very few relevant articles that could not be categorized based on the scheme developed here.

In addition, the categories and subcategories presented here support our supposition that the three disciplines operate independently and use largely different strategies for promoting change. This finding supports our expectation that interdisciplinary work involving researchers from SER, FDR, and HER might be productive since each group can bring different sets of knowledge. There is no evidence that we have missed an important disciplinary community.

Another important trend is the presence of common weaknesses across all four change categories and all three research communities. Many of the articles did not present convincing evidence to support the conclusions drawn and many articles did not build arguments and change strategies from the research literature. One possible reason for this situation is that since the literature is distributed in a wide variety of locations (the 295 articles in our database represent 108 distinct journals) it is difficult for authors in this area to find out about previously published work. This finding suggests that there is substantial need for synthesis work such as the work represented by this project. It also suggests that there is substantial need for work and effort focused on producing high quality studies that build on previous work.

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REFERENCES

1. Center for Science, Math, and Engineering Education, *Transforming Undergraduate Education in Science, Mathematics, Engineering, and Technology*, Washington, D.C.:National Academy Press, 1999.
2. D. Bok, *Our Underachieving Colleges: A Candid Look at How Much Students Learn and Why They Should Be Learning More*, Princeton, NJ: Princeton University Press, 2006.; Boyer Commission on Undergraduates in the Research Universities, *Reinventing Undergraduate Education: A Blueprint for America's Research Universities*, Menlo Park, CA: Carnegie Foundation for the Advancement of Teaching, 1998.; J. Handelsman et al., "EDUCATION: Scientific Teaching," *Science* **304** (5670), 521-522 (2004).
3. C. Henderson, A. Beach, N. Finkelstein, and R. S. Larson, "Preliminary Categorization of Literature on Promoting Change in Undergraduate STEM," paper presented at the Facilitating Change in Undergraduate STEM symposium, Augusta, MI, (2008). <<http://www.wmich.edu/science/facilitating-change/PreliminaryCategorization.pdf>>