Response to PROMOTING EVIDENCE-BASED CHANGE IN UNDERGRADUATE SCIENCE EDUCATION, A Paper Commissioned by the National Academies National Research Council, Board on Science Education by Ann E. Austin, March 1, 2011

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Thank you for the thorough and thoughtful essay on "promoting evidence-based change in undergraduate science education." It is well organized and written and the arguments are clear and persuasive. I am convinced that providing insights on how to promote evidence-based change is a critically important aspect of our work on the DBER committee. I appreciate the opportunity to reflect on the essay and to provide a response. I will summarize the arguments, add connections to other activities and initiatives that are congruent, and provide some thoughts on how to strengthen the arguments.

Scholars have been researching and writing about change in higher education for many years and as with the body of knowledge on evidence-based promising practices for undergraduate STEM education there is extensive documentation on change in higher education. In both cases; however, there is a large gap between knowing and doing. I hope that in our conversation today and in our report we can help close those gaps.

I'd like to start with a little personal history, and my take on the current sense of urgency. About eight years ago at a Center for the Advancement of Engineering Education (CAEE) Advisory Board meeting Elaine Seymour asked the question, "What is your theory of change?" She claimed later that she was looking for a brief answer; however, my colleagues and I dug deeply into the change literature and wrote a paper titled Engineering change (Smith, et.al., 2004). We primarily emphasized models of change and argued that there are so many competing ideas that an accepted theoretical framework hasn't been developed. As a community of researchers I think we implicitly embraced the notion that our role was to do world class research and the results would change or at least influence practice (and I think Elaine was trying to get us to question that assumption). The final report for the CAEE project was published recently and it contains the results of one of the largest-scale systematic studies of engineering education ever done. (Atman, et.al. 2010).

The question of change in STEM undergraduate education is currently front and center. I hope the committee has had a chance to read the Wieman, Perkins and Gilbert's *Change* article (in the Briefing Book), "Transforming science education a large research universities," which was published about a year ago. The authors' assumptions of the science education incentives change model (p. 8) have a high level of congruence with the arguments in the Austin paper. Currently Carl Wieman is Associate Director for Science, White House Office of Science and Technology Policy (OSTP) and his talk at the NSF CCLI/TUES PI meeting in January stressed "thinking like a scientist/engineer" to achieve better learning and, especially, measuring impact. Myles Boylan noted in his presentation "The Federal Environment for STEM Education Programs: Implications for TUES" that OSTP is actively involved in the evaluation of

STEM Ed programs at NSF and that OMB is also taking a detailed interest. Boylan summarized NSF Responses (New Emphases):

- Innovation = transformative research & education
- Explore promise of cyber-enabled learning; NSDL
- Renewed concern about sustainability of projects
- Examined & redesigned CCLI, NSDL
- Renewed emphasis on assessment and evaluation needed to capture value derived from a large variety of CCLI/TUES projects
    - New materials
    - New teaching methods
    - Faculty professional development

The arguments presented in the Taking a Systems Approach section (summarized in Austin (2010) Figure 1) – Relevant Individual Characteristics, Contexts affecting Faculty Practice, and Levers Impacting Faculty Members' Teaching Practice are extremely important for changing the landscape of undergraduate teaching and learning in STEM disciplines. I concur with the recommendations and offer some ideas on how I think the arguments for a systems approach can be strengthened.

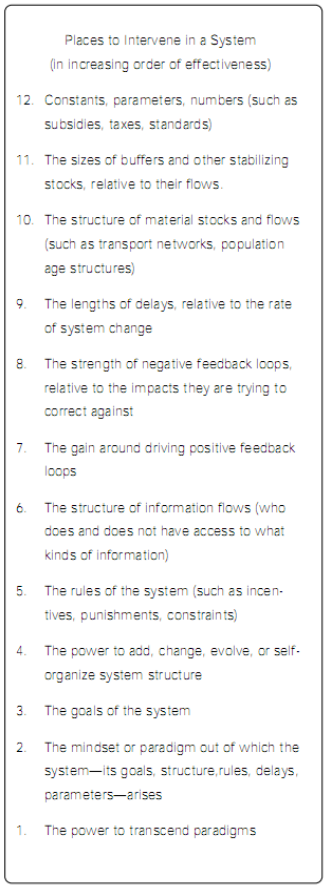

Figure 1 Meadows (1999)

The idea of systems has been with us for more than 50 years. One pivotal event was the MIT Cybernetics Group which met regularly between 1946 and 1953. These meeting prompted many influential ideas and fostered the development of many groups, such as Forrester's World Dynamics group (Heims, 1991). My first exposure to systems was in a systems analysis course in 1967 where operations research was emphasized. I taught civil engineering systems for over 20 years and increasingly tried to de-emphasize operations research and stress "systems thinking." Peter Senge's work was influential as was Russell Ackoff's. Probably the most influential work was Donella Meadows (1999, 2008) and especially her emphasis on "Leverage points – Places to intervene in a system" (See Figure 1.)

Systems approaches and systems thinking are still not common in higher education or anywhere else for that matter. I have puzzled about this gap for some time. Currently, I am encouraged by the work on complexity theory and complex adaptive systems. Traditional systems approach work focused on optimization and developed lots of strategies for addressing "Mt. Fuji" and "rolling landscape" problems. Some problems are "dancing landscape" problems that are not easily addressed by traditional optimization approaches; however, complex adaptive systems can address these problems (Miller & Page, 2007; Page, 2009). Problems that involve human behavior (like teaching and learning problems) are likely better represented by complexity theory since people adapt and the

systems are dynamic, i.e, “dancing landscape” problems.

On page 3 Cohen and March (1991) “The process of choice” is mentioned and the reference to James March reminded me of his 1991 article “Exploration vs. exploitation in organizational learning.” This idea has re-emerged in the business literature (Martin, 2010), innovation literature (Govindarajan and Trimble, 2010), and the complexity literature (Page, 2009). One of the fundamental challenges to change is managing the trade-off between (1) supporting on-going operations and (2) supporting innovation, which are described by March (1991), Martin (2009), and Page (2009) as the explore-exploit trade-off and by Govindarajan and Trimble (2010) as the Performance Engine vs. Innovation. The pressure to support on-going operations (or to maintain the status quo) is enormous, and change requires embracing innovation within the context of supporting on-going operations. Govindarajan and Trimble (2010) provide a lot of guidance on how to do this.

The documentation on an academic approach to change and change in the academy is thorough; however, there is a much broader world of literature on change that may be relevant. Change has been emphasized by philosophers (Kaufmann, 1973, for example) and by many in the business and leadership sector (Schein, 2010, for example). Our engineering change article (Smith, et.al, 2004) summarizes the prominent approaches to change. As a third generation Lewinian I’m partial to Lewin’s (1947) three-stage model, which is based on a model of quasi-stationary equilibrium:

1. a stage of unfreezing
2. a stage of changing, and
3. a stage of refreezing

Schein (2010, p. 300) elaborated on these stages as follows:

Stage 1. Unfreezing: Creating the Motivation for Change

- Disconfirmation
- Creation of survival anxiety or guilt
- Creation of psychological safety to overcome learning anxiety

Stage 2. Learning New Concepts, New Meanings for Old Concepts, and New Standards for Judgment

- Imitation of and identification with role models
- Scanning for solutions and trial-and-error learning

Stage 3. Internalizing New Concepts, Meanings, and Standards

- Incorporation into self-concept and identity
- Incorporation into ongoing relationships

Schein (2010) argues that “all human systems attempt to maintain equilibrium and to maximize their autonomy vis-à-vis their environment” and that this is a principal barrier to change.

Leading change in the academy or anywhere else is still a mystery and merits attention from DBER researchers. Books on change continue to emerge at a remarkable rate and some of them are from extraordinary scholars, such as Bob Kegan (Kegan & Lahey, 2009); however, my sense is that we have little idea how to foster systemic change in STEM education.

Another voice in the quest for change comes from the innovation community. My favorite definition of innovation is "the adoption of a new practice in a community" (Denning & Dunham, 2010) and they elaborate on strategies for ideas that will be developed into practices in communities. Innovation like change is a popular topic; Denning and Dunham (2010) noted that over 9300 books on Amazon.com have "innovation" in their title. For the past two years the National Academy of Engineering has sponsored the Frontiers of Engineering Education symposium, which is focused on innovation (http://www.nae.edu/Activities/Projects20676/CASEE/26338/35816/FOEE.aspx). Below is a list of the participant outcomes:

Participants will strengthen their professional capacity for engineering education innovation by—

- Identifying and understanding how to apply identified best practices in engineering education;
- Developing new ideas to advance their innovations in engineering education;
- Developing an understanding that engineering educational innovation should be guided by the evolving evidence-based body of knowledge on engineering learning, in part established through research in engineering education;
- Establishing long-lasting professional relationships with those attending the symposiums, and through those relationships establish new or broadened networks with other educational innovators;
- Becoming agents of change to help advance the U.S. capacity for engineering education innovation

Summarizing and synthesizing the innovation literature as it pertains to STEM education can strengthen the arguments for change in the DBER report.

Concluding Remarks

Change is difficult especially in mature institutions such as colleges and universities. The precursors of modern universities started in Italy, France and England in the 11th and 12th Centuries. Universities have persisted longer than almost all other institutions (especially businesses) except perhaps for religious institutions. The longevity and robustness of colleges and universities may be due in part to their resistance to change; however, this resistance may also foreshadow their irrelevance and perhaps their demise.

Very few books on change in higher education emphasize complexity theory. One exception is Harlan Cleveland's *Nobody in Charge: Leadership for the Management of Complexity.* Cleveland served in the State Department in the Johnson Administration, was the founding Dean of the UMn Humphrey Institute of Public Affairs and was President of the University of Hawaii. Cleveland argues that leadership in the complexity era requires:

- A lively intellectual curiosity – because everything is related to everything else
- A genuine interest in what other people think and why they think that way
- A feeling of responsibility for envisioning a future that's different from straight-line project of the present
- A hunch that most risks are there not to be avoided but to be taken
- A mindset that crises are normal, tensions can be promising, and complexity is fun
- A realization that paranoia and self-pity are reserved for people who *don't* want to be leaders
- A sense of *personal* responsibility for the *general* outcome of your efforts
- A quality of "unwarranted optimism"

On that note of "unwarranted optimism," Barbara Ward, British Historian and early activist in the environmental movement noted, "we do not know the future; we have the duty to hope."

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