Seven Ideas for Effective Curricular Renewal

Authors:

Jeff Froyd, Texas A&M University, TAMU 3405, College Station, TX 77843-3405, froyd@tamu.edu

Abstract — *The Foundation Coalition, a NSF Engineering Education Coalition, was established as an agent of systemic renewal for the engineering educational community. Seven ideas have guided curricular renewal, classroom design, and faculty development projects for the past ten years and will guide curricular research and renewal for the next ten years. Reflecting the seven ideas in light of past accomplishments provides valuable foundations for future efforts to improve engineering education.*

Index Terms — *Curriculum integration, underrepresented groups, assessment and evaluation, student teams*

INTRODUCTION

The National Science Foundation (NSF) developed the Engineering Education Coalition (EEC) program to stimulate bold, innovative, and comprehensive models for systemic reform of undergraduate engineering education. Through the EEC program groups of universities and colleges of differing characters formed Coalitions in order to become change agents amidst the engineering education community. Goals for systemic reform included increased retention of students, especially underrepresented groups such as white women and underrepresented minorities, improved introductory experiences in engineering, active experiential learning experiences such as artifact dissection, and multidisciplinary capstone design experiences. First funded in 1993, the Foundation Coalition (FC, http://www.foundationcoalition.org) was one of the six Coalitions and currently consists of six partner campuses: Arizona State University, Rose-Hulman Institute of Technology, Texas A&M University, University of Alabama, University of Massachusetts Dartmouth, and University of Wisconsin Madison. FC partners agreed on seven ideas to guide their manifold efforts to catalyze improvement in engineering education:

- **Curriculum integration and learning communities:** helping students make connections between various disciplines and between academic topics and lifelong careers and helping them to build learning relationships with other students
- **Continuous improvement through assessment, evaluation, and feedback:** develop assessment processes to collect data on the impact of changes to the curricula and learning environments, reaching conclusions about the efficacy of those changes and making improvements where indicated
- **Increasing the participation (recruitment, retention, and graduation) of white women and underrepresented minorities in engineering:** if the learning environment works for a more diverse student body, then it will be a better learning environment for all students
- **Organizational development and change:** making significant curricular changes requires a complex, thoughtful change model that is based on research and experience
- **Technology-enabled learning:** creating learning environments in which routine access to ubiquitous technology is assumed and the revision of learning activities is based on this assumption
- **Active and cooperative learning:** increasing student participation in and ownership of their learning
- **Student teams in engineering:** helping students develop their abilities to work within and lead teams requires more than assigning students to group projects

As the EEC program draws to a close, reflecting on each of the seven ideas in light of past accomplishments may provide valuable starting points for future efforts to improve engineering education. For each of the seven ideas, the paper will review past research and suggest opportunities for future efforts.

CURRICULUM INTEGRATION AND LEARNING COMMUNITIES

The engineering approach links concepts and resources together "to create what has never been" [1]. Several reasons have been offered to motivate more integrative learning experiences: the integrative nature of engineering practice [1]-[3]; integrative, multi-disciplinary approaches are required to address complex sociotechnical challenges; and learning to be broadly applicable requires a conceptual framework within which each learner builds complex relationships among different components of knowledge [4,5]. Across the FC, partner campuses initiated pilot curricula [6]-[11] in which one of the goals was that students would make connections between subjects and connections between subjects and future careers. In addition, several institutions beyond the FC have also initiated integrated curricula [12]-[17]. Results from several of the early integrated curricula showed that participating students also made social connections [18]. Other institutions have initiated learning communities in which students are encouraged to make academic and social connections [19, 20]. Comparing the goals and methods for integrated curricula and learning communities show far more commonalities than differences; in fact, the two initiatives are different names for the same effort. Counting both integrated curricula and learning communities, numerous initiatives have been made to help students make more connections within their learning environments. Results have indicated increased retention [21], including increased retention for underrepresented groups such as white women and underrepresented minorities [22, 23], and improved grade point averages in courses subsequent to the learning communities [6].

Despite improvement demonstrated by integrated programs, the goal of helping students make greater connections among the subjects that they are studying has not been refined into published sets of learning objectives that reflect the goal. Without learning objectives, with their precise descriptions of expected performance behaviors under carefully delineated conditions, assessment instruments and processes that might ascertain degrees to which students have demonstrated integrated learning cannot be developed. Therefore, integrated programs have not demonstrated any differences in performance as far as integrated learning between students who participated in integrated programs and students who have not participated in integrated programs.

One of the opportunities for further research is to develop a set of learning outcomes associated with students making and applying connections. Once a set of learning objectives has been developed, the next step would be to develop assessment instruments and processes associated with the learning objectives. Then, student learning might be evaluated with the assessment instruments and processes. With this infrastructure in place, interventions that are intended to improve integrated learning might be tested to determine whether improvements in integrated learning were observed. Work on developing learning outcomes and assessment instruments and processes might draw upon recent research on transfer of learning [24]-[26]. Greater understanding of integrative learning and how it might be recognized could be valuable for enhancing student capabilities for important synthetic outcomes such as engineering design, problem solving, framing sociotechnical challenges, and confronting ethical dilemmas.

CONTINUOUS IMPROVEMENT THROUGH ASSESSMENT, EVALUATION, AND FEEDBACK

The infrastructure to support assessment of curricular innovations, especially on the scale as implemented in many EEC programs, was virtually non-existent when the EEC program was initiated 1990. The Accreditation Board for Engineering and Technology (ABET) had not revised its Engineering Criteria; the importance of learning outcomes together with assessment instruments and processes was not widely recognized; very few faculty members were knowledgeable about assessment and evaluation. Gradually, the critical role of assessment became recognized. Adoption of the new Engineering Criteria by ABET in the mid 1990s played a pivotal role in bringing about near-universal recognition of the importance of assessment. Recognition of its importance has stimulated development of the infrastructure to support assessment of learning outcomes. Every Coalition invested increasing resources, both to assess its initiatives and to support further development of assessment instruments and processes, such as Team Developer [27], mining student information databases, and concept inventories. Even with outcomes-based ABET Engineering Criteria and efforts by the Coalitions, the infrastructure for assessment of critical capabilities (e.g., design, problem-solving, lifelong learning) has not yet matured to the point that would support systemic reform in engineering education.

Today, numerous instruments exist or are being developed to assess conceptual understanding of many areas in engineering science. Motivated by the success of the Force Concept Inventory [28,29] that examines conceptual understanding of Newton's laws of motion, science and engineering faculty have developed or are developing similar instruments [30]-[44]. Engineering educators are using concept maps to obtain clearer pictures of the relationships that students develop among concepts [45,46]. Progress in reliably and validly assessing complex outcomes such at the program outcomes listed in Criterion 3 of the ABET Engineering Criteria is being made. For example, the Transferable Integrated Design Engineering Education (TIDEE) project has developed a set of instruments and processes for assessing knowledge and skills associated with engineering design [47]. Team Developer [27] provides an online set of assessment tools to help students develop their skills for teamwork. Although many instruments and processes have been created, considerable work remains until the assessment and evaluation infrastructure will support continuous improvement in engineering education.

INCREASING PARTICIPATION OF UNDERREPRESENTED GROUPS

The percentages of Caucasian women, African Americans, Hispanics, and Native Americans, who are enrolled in undergraduate engineering programs, graduate with engineering degrees, are enrolled in graduate engineering programs, earn graduate degrees, and practice as engineering faculty members, are still low, has not grown rapidly enough during the past 15 years, and must be increased. William Wulf, president of the National Academy of Engineering, makes a case that the quality of engineering designs is adversely affected by the lack of diversity in the engineering workforce [48]. Others argue for increased diversity on the basis of social and economic equity. Others indicate that increased diversity is necessity to meet the need for a growing number of engineering graduates. For these and other reasons, many efforts have been made and are being made to increasing the participation of underrepresented groups in engineering.

Increasing participation implies that changes will be made. The question then becomes who or what changes. For many years, efforts such as Women in Engineering and Minority Engineering Programs have focused on changing student participants: raising their awareness of the opportunities offered by engineering or helping them adjust to the learning environments available in engineering. Virginia Valian, in her book [49], offers a different, and potentially enormously helpful, perspective. She presents the case that under representation of women (and without too much extrapolation, all underrepresented groups) is caused by disadvantage that is accumulated in small, almost unnoticeable, minuses over time. Further, she states that the small minuses are caused by gender schemas: sets of implicit hypotheses about sex differences. Following this theory, increasing participation of underrepresented groups requires changes in the learning environments in engineering and the components that compose the learning environments, i.e., faculty members and curricula. Recognizing the opportunity is both empowering and daunting. It is empowering because the components that need to be changed: curricula and faculty members, are components that engineering faculty members control. It is daunting because it implies that we must change. Curricula might change to offer more cooperative, as opposed to competitive, and integrative learning environments. Faculty members might change as they understand their gender schemas that have been implicit and unrecognized. These opportunities for change might be some of the most exciting challenges in the next decade.

ORGANIZATIONAL DEVELOPMENT AND CHANGE

After observing curricular change processes on seven different campuses in the first five years (1993-98) of the Foundation Coalition (FC), the management team concluded that the process of curricular change was so important and so inadequately delineated that it merited elevation in status to become one of the key ideas that should guide further curriculum research and development in the second five years (1998-2003). To learn more about curricular change, a qualitative study was initiated in 2001 and included over 150 interviews with faculty members and administrators at the FC partner institutions. One of the findings from the study was that faculty members who were involved in the curricular change process gradually changed their pictures of what needed to be changed and how these changes might be brought about [50]. This finding echoed Seymour who called for explicit articulation of the change theories that underlie initiatives to improve education in science, technology, engineering, and mathematics (STEM) [51]. Also inherent in the change process is resistance. To innovators who are trying to move a specific change or a particular set of changes forward, resistance might be seen as negative. However, as Senge et al describe in their book [52] resistance is inevitable for any change at either the natural or human level. Since resistance is inevitable, its occurrence should not be regarded as a sign that the change will be unsuccessful or as a negative force pushing against the change. Mauer encourages change agents to view change not as efforts to overwhelm or steamroll resistance, but instead as processed in which change agents work to understand the nature of resistance and engage it actively [53]. For example, both Seymour [51] and Clark et al [50] attempt to show that positive assessment results alone will not overcome resistance. Instead, change agents should prepare multiple strategies.

Although culture is frequently mentioned as a source of resistance and cultural change is frequently called for in systemic reform of engineering education, greater clarity about both is needed before efforts to change culture. For example, the following three quotes illustrate how culture permeates and influences conversations and decision and the scope of efforts required to change culture.

> *Transformation is as much about getting people to think differently as it is about anything else. Forging new collective understandings and creating new beliefs about institutional activities and people's roles are essential to transformation and, we found, more important than changing structures, creating reward incentives, aligning budgets, or making and implementing difficult decisions. A key part of transformation is changing mind-sets, which, in turn, alters behaviors, appreciations, commitments, and priorities. Over the course of transformation efforts, people develop new beliefs and interpretations and adopt new ways of thinking and perceiving that help create the foundation of significant change. Transformation is about making new sense. Without exploring what the changes mean for the institution and capturing the minds and hearts of faculty, staff, students and trustees, institutional change will be limited to new organizational structures and policies that may not add up to transformation [54, chapter 3].*

Organizational culture is an emergent result of continuing negotiations about values, meanings and properties between the members of that organization and with its environment. In other words, culture is the result of all the daily conversations and negotiations between the members of an organization. …If you want to change a culture you have to change all these conversations —or at least the majority of them. [55]

"Culture eats change for breakfast" [56].

Greater understanding of change theories, resistance, culture and cultural change, and the role of leadership in change is required in order to become more proficient in facilitating sustainable change.

TECHNOLOGY-ENABLED LEARNING

Prior to creation of the EEC program, laboratory experiences were essential components of the learning environment of every engineering student. So, technology was an integral element of engineering educational approaches. Continuing technological developments have constructed new opportunities and numerous opportunities have been and are being explored. Simulation software has been used to augment or replace laboratories and help students explore more design alternatives. Multimedia technology has been used to supplement or replace lectures. Telecommunication technologies have allowed many approaches to distance learning to be explored. Online assessment instruments provide the potential for more rapid feedback to student about their performance. Presentation technologies and online assessment approaches have been combined to construct self-paced and/or distance learning packages. Powerful computational packages allow students to perform numerous calculations and manipulations more rapidly and more accurately. Although number approaches have been explored, widespread adoption of any innovative approach has not occurred, except that just about every student now uses a powerful calculator, even on examinations.

From the all the activity that is occurring as numerous approaches to enhancing education via technology are being explored, two key questions might help to organize approaches being tried and results being generated. The first question is who uses the technology? Are students using technology as they work to learn or are teachers using technology to deliver education? The second question asks if technology is actually enhancing student learning. Answers to each of the questions helps describe how the technology is being applied and whether the technology as applied has promise for more widespread application. Deeper exploration of the two questions requires more space that the present paper permits.

ACTIVE/COOPERATIVE LEARNING

Active learning encompasses several approaches to teaching: collaborative learning [57], cooperative learning [58], and problem-based learning [59], that attempt to engage students in more ways than taking notes. For example, Bonwell and Eison indicate that when faculty members are using active learning "[they] are involved in dialog, debate, writing, and problem solving, as well as higher-order thinking, e.g., analysis, synthesis, evaluation" [60]. Interest in active learning and related approaches has grown since the EEC program began. For example, at least 280 papers in the proceedings of the Frontiers of Education Conference (FIE) since 1995 use the phrase "active learning," at least 220 papers use the phrase "cooperative learning," at least 31 papers use the phrase "active and cooperative learning," and at least 82 papers use the phrase "problem-based learning." Although there is overlap among these four sets of papers, the FIE proceedings demonstrate considerable interest in active pedagogical approaches. In addition, several studies have been published since 1990 that demonstrate superior efficacy of one or more pedagogical approaches that are found under the umbrella of active learning. Prince, in a recent paper [61] has analyzed many of the studies and provided cogent synthesis.

The challenge in this key area is to find more ways to engage faculty members so that they rethink (referring to the recognition by Eckel and Kezar [54] that transformation requires thinking differently) their assumptions and conceptions of learning and teaching. Faculty members are at different stages in the process of rethinking and different resources are required to facilitate transitions to subsequent stages [62]. Although workshops, books, and articles on active learning are available, more compact resources that can be read in short amounts of time and that synthesize available results and resources might facilitate transitions to levels of greater engagement for faculty members who are unwilling to invest much time in finding out more about active and cooperative learning.

STUDENT TEAMS IN ENGINEERING

Today, engineers work in teams and engineering students need to be prepared to work in teams. ABET, for example stipulated that engineering graduates should have "an ability to function on multi-disciplinary teams." Over 800 papers in the FIE proceedings refer to "teams" and most capstone design courses have students work in teams. Although the engineering education community recognizes the importance of team skills, there is less widespread recognition that development of team skills requires more than simply participation in student teams [63, 64]. More work is required to explicitly identify the teams required for functioning on multi-disciplinary teams, e.g., interpersonal communication (listening and speaking), conflict management, decision making, leadership, etc., and developing learning objectives and assessment instruments and processes that are associated with these skills. Then, resources need to be developed to support faculty members as they address these learning objectives with their students. Resources have been developed by the BESTEAMS project [65]-[68], the Foundation Coalition [60], and many others. However, faculty members still need more accessible resources that are more closely connected with the concepts and outcomes that they are teaching in their courses.

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