Engineering Change

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Abstract: Calls for change abound in engineering education. The community is responding with innovations at many different levels. The effectiveness and long-term "staying power" of any new development is likely to increase if the innovators are explicit about the model of change they are adopting. Many such models are relevant for the engineering education community. In this paper we present a list of change models, describe three of them in detail, and briefly describe how we are conceptualizing one approach to change we are taking in the newly funded Center for the Advancement of Engineering Education.

Introduction

Calls for change in engineering education are a common theme among leaders in engineering education (Bordogna, 2003; Fromm, 2003; Jackson, 2003; Wulf, 1998, 2002; Wulf and Fisher, 2002). One of the authors of this article, Karl Smith, began exploring changes in engineering education about 10 years ago and gave a series of keynote presentations with titles such as "Engineering education: Pressures to change, current trends and future directions." Smith listed the pressures to change from the following organizations and groups at the Australasian Engineering Education Conference in 1998:

- Legislators (in public institutions)
- National Science Foundation: Career Development Award, Shaping the Future
- Professional Accreditation – ABET: Assessment, Synthesis & Design
- Financial – especially the growing gap between the falling public support and the rising costs
- Employers and Workforce Development Agencies: Workplace Basics, Global Engineer
- University Administration Professional Organizations: Renewing the Covenant, Greater Expectations
- Boyer Commission Reports: Educating Undergraduates in the Research Universities, Scholarship Reconsidered
- Educational Research: Active, Interactive & Cooperative Learning, Inquiry & Problem-Based Learning

Comparison of the old and new paradigms of engineering education also implies and provides grounds for change. In 1991 Johnson, Johnson & Smith provided the initial comparison of old and new paradigms of engineering education. Smith and Waller (1997) updated the comparison and both have become widely-cited in the engineering education community (Table 1).

Table 1. Comparison of old and new paradigms for college teaching, (adapted from Johnson, Johnson and Smith, 1991).

	Old Paradigm	New Paradigm
Knowledge	Transferred from faculty to students	Jointly constructed by students and faculty
Students	Passive vessel to be filled by faculty's knowledge	Active constructor, discoverer, transformer of knowledge
Mode of Learning	Memorizing	Relating
Faculty Purpose	Classify and sort students	Develop students' competencies and talents
Student Goals	Complete requirements, achieve certification within a discipline	Grow, focus on continual lifelong learning within a broader system
Relationships	Impersonal relationship among students and between faculty and students	Personal transaction among students and between faculty and students
Context	Competitive/individualistic	Cooperative learning in classroom and cooperative teams among faculty
Climate	Conformity/cultural uniformity	Diversity and personal esteem/ cultural diversity and commonality
Power	Faculty holds and exercises power, authority, and control	Students are empowered; power is shared among students and between students and faculty
Assessment	Norm-referenced (i.e., graded "on the curve"); typically multiple choice items; student rating of instruction at end of course	Criterion-referenced; typically performances and portfolios; continual assessment of instruction
Ways of Knowing	Logico-scientific	Narrative
Technology Use	Drill and practice; textbook substitute; chalk and talk substitute	Problem solving, communication, collaboration, information access, expression
Teaching Assumption	Any expert can teach	Teaching is complex and requires considerable training

In a 1999 presentation at the ABET annual conference Smith (1999) presented the following key features of the new paradigm:

1. Defining educational objectives, facilitating development of critical and creative thinking and problem-solving skills
2. Active learning (individual and group activities in class)
3. Structured cooperative learning (including multidisciplinary teamwork and facilitating development of written and oral communication skills)
4. Writing and (multidisciplinary) design across the curriculum
5. Inquiry and discovery learning (problem-based, case- based)

6. Teaching to diversity (different learning styles, ethnicities, genders)
7. Appropriate use of technology (tools, simulation, exploration).

The winds of change in engineering education have been blowing for some time, and the question arises "Why hasn't more change occurred faster?" Wulf's (2002) "hypothesis is simply that the faculty don't believe that change is needed. They are following the wise adage, 'if it ain't broke, don't fix it.' If one hasn't had recent experience in industry, …, and if the change is a mosaic in multiple dimensions whose pattern is hard to discern, then the fact that it's 'broke' is not easy to see." This allegation of resistance from faculty is ironic given Koen's (2003) claim that change is fundamental to engineering; in fact it is an integral part of his definition of the engineering method – "the use of heuristics to cause the best possible change in a poorly understood situation within the available resources."

Pressures for change continue to come from many sectors. And these calls for change increasingly bring up the need to "ensure that *all* undergraduates increase their knowledge and understanding of STEM (Science, Technology, Engineering, Mathematics) and the relevance of these disciplines to other areas of learning and human endeavors" (NRC 2002: 11). Predicted demographic changes in the student population present a compelling case for change (BHEF 2002; NCES 2002, 2003; NSB, 2002) and the importance of retaining the students we do attract to engineering (Clewell & Campbell, 2002; Seymour and Hewitt, 1997).

The major question then is how to achieve change in engineering education. For us, this is a theoretical question as well as a practical question. It is an important part of the mission of the Center for the Advancement of Engineering Education (CAEE) to provide research-based evidence as part of the foundation for change in engineering education as well as a thorough exploration of models and best practices for change.

In this brief article we provide a (1) brief review of change literature, especially in higher education; (2) a summary of selected models of change; and (3) a case study of one approach to change at CAEE.

Exploring Change Models

The purpose of this section is to explore the quantity and variety of change models available as resources for engineering educators. Change models have been developed in disciplines as diverse as philosophy of science, organizational development, business management, educational research, and teacher education. This wide array of sources can be perplexing for educators seeking an applicable change model and challenging those who need to identify which model appropriately describes their current context. Rather than thinking of this as a bewildering array of choices and possibilities, we are using this as an opportunity to learn what others have accomplished and present it to our colleagues who are charting a similar course. Six main categories of theories of change assist in understanding, describing, and developing insights about the change process (Kezar, 2001):

1. Evolutionary
2. Teleological
3. Life cycle
4. Dialectical

5. Social cognition
6. Cultural

Kezar's list is based in part on Van de Ven and Poole's (1995) article "Explaining development and change in organizations," which summarized four basic theories that serve as building blocks for explaining process of change in organizations – life cycle, teleology, dialectics, and evolution.

Table 2 lists change models we have been exploring. The list includes models of change in higher education, education innovation models, educational and organizational development models, and models from the science education reform literature.

Table 2. Scholarship on change.

Models of change:
• AACU (2002) Greater Expectations: A new vision for learning as a nation goes to college
• Argyris and Schön (1974) Theory in Practice: Increasing professional effectiveness
• Astin & Astin (1996) A social Change Model of Leadership Development
• Astin & Astin (2000) Leadership Reconsidered
• Boyatzis, Cowen & Kolb (1994) Innovations in Professional Education
• Boyer (1990) Scholarship Reconsidered
• Christensen (1997) The Innovator's Dilemma (Disruptive technologies)
• Davis (2002) "Change is hard": What science teachers are telling us about reform and teaching learning of innovative practices.
• Doerr & Lesh (2003) A modeling perspective on teacher development
• Feldman (2000) Decision making in the practical domain: A model of practical conceptual change.
• Froyd (2000; and Froyd et al. 2000) Faculty change readiness model
• Gess-Newsome, Southerland, Johnston & Woodbury (2003) Educational reform, personal practical theories, and dissatisfaction: The anatomy of change in college science teaching.
• Johnson & Johnson (1994) Cooperative Learning Model
• Little (1982) Three Key Conditions for Change
• Palmer (1998) "movement approach" The Courage to Teach
• Rogers (2003) Diffusion of Innovation
• Schein (2002) Models and tools for stability and change in human systems
• Seymour (2002) Tracking the Processes of Change
• Wilson & Daviss (1994) Redesigning Education

In subsequent paragraphs, we divide change models into two kinds: stage (or phase) models and complexity models of change. These ideas give us some language for characterizing the various change models presented in Table 2.

<u>Stage Models of Change</u>

Many of the applied step/phase models can be traced back to Lewin's (1952) 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

The stages of evolutionary and revolutionary change identified by Kuhn (1962) in his treatise on the development of scientific theories are so widely known that his terminology has become widespread in the academy. Periods of evolutionary change, or the state of "normal science," as Kuhn (1962) referred to it, can be planned and managed. Kuhn suggested that revolutionary change, or "revolutionary paradigm" shifts, cannot be planned and managed because they are unpredictable and relatively swift compared to the state of normal science.

Numerous authors, such as Chin and Benne (1985) and Schein (2002) have expanded on Kuhn's two broad categories. Schein (2002), for example, described three types of change:

1. Natural evolutionary changes
2. Planned and managed changes
3. Unplanned revolutionary changes

Probably the most famous step model of change is Rogers' (2003) *Diffusion of Innovation* that describes diffusion as the process by which (a) an innovation (b) is communicated through certain channels (c) over time (d) among the members of a social system. Rogers conceptualizes five steps in this process: 1) knowledge, 2) persuasion, 3) decision, 4) implementation, and 5) confirmation. Rogers is famous for the S-curve relationship between time and the number of adopters. Rogers writes that "The dominant viewpoint is that social change is caused by both *invention* (the process by which a new idea is discovered or created) and diffusion, which usually occur sequentially."

Clearly, defining or using a series of steps to create or manage change is a useful heuristic, however, there are many offered in the literature and they all seem idiosyncratic. Argyris (2000) describes several approaches involving a series of steps, but dismisses them as "nonactionable advice."

<u>Complexity Change Models</u>

Several organizational researchers have summarized the limitations of stage theories for achieving change and instead focus on the inherent nature of change in organizations and on microclimates for change (Axelrod, 2002; Feldman, 2000; Orlikowski, 1996; Orlikowski and Hofman, 1997; Tsoukas and Chia, 2002). Mintzberg, Ahlstrand, & Lampel (1998) summarized ten management schools of thought on change (design, planning, positioning, entrepreneurial, cognitive, learning, power, cultural, environmental, and configuration) and concluded "the best way to 'manage' change is to allow it to happen" (p. 324), "to be pulled by the concerns out there rather than being pushed by the concerns in here." These ideas are also presented in Mintzberg and Lampel 1999.

Fullan (2001) in *Leading in a Culture of Change*, summarizes the problems with morphologies by offering several authors' steps to change, but he eventually draws similar conclusions that change cannot be managed. Instead, he suggests that change can be understood and perhaps led, but it cannot be controlled.

This less directed approach to change is also supported by earlier work of complexity theorists, such as Kauffman and colleagues at the Santa Fe Institute. Kauffman (1991, 1995) notes that change takes place spontaneously, as a result of what he and his colleagues refer to as an "autocatalytic" process. The concept of autocatalytic processes generating change is largely attributed to 1977 Chemistry Nobel Laureate Prigogine (Prigogine & Stengers, 1984). Jaafari (2003) provides an excellent summary of complex society and some of its key characteristics – open systems, chaos, self-organization, and interdependence – within a project management framework.

More recent change research appears to blend the two approaches. For example, Gosling and Mintzberg (2003) note the "dominant model of managing change is Cartesian: Action results from deliberate strategies, carefully planned, that unfold as systematically managed sequences of decisions." However, they counter, "change, to be successful, cannot follow some mechanistic schedule of steps, of formulation followed by implementation. Action and reflection have to blend in a natural flow."

These two primary categories of change, staged and complexity, provide us with a useful framework for organizing the various models of change.

In the subsequent section, we further constrain our investigation of change models for engineering education by providing overviews of models that we think are relevant to the goals of the CAEE.

Examples of Selected Change Models

In this section we provide a summary of three approaches to change – Palmer's Movement Approach, Johnson & Johnson's Cooperative Learning Implementation Approach, and Seymour's Tracking Change Synthesis.

<u>Parker's Movement Approach - A Stage Model</u>

Parker Palmer (1997, 1998) proposed a "movement approach" to change. He introduces the movement approach with the following question:

> *"Is it possible to embody our best insights about teaching and learning in a social movement that might revitalize learning"?* -- Parker Palmer

Palmer's movement approach to educational reform consists of four stages:

- *Stage 1.* Isolated individuals make an inward decision to live *"divided no more,"* finding a center for their lives outside of institutions.
- *Stage 2.* These individuals begin to discover one another and form *communities of congruence* that offer mutual support and opportunities to develop a shared vision.
- *Stage 3.* These communities of congruence start *going public*, learning to convert their private concerns into the public issues they are and receiving vital critiques in the process.
- *Stage 4.* A system of *alternative rewards* emerges to sustain the movement's vision and

to put pressure for change on the standard institutional reward system.

Engineering education reform, judged from Palmer's stages, is somewhere between stage 2 and stage 3. Smith and MacGregor (2000) interpreted the adoption of small-group instruction and learning communities using Palmer's framework, as well as using Rogers' diffusion model.

Implications for supporting change

The research and development efforts of engineering education researchers can help provide communities of congruence (Stage 2) and can help these communities go public (Stage 3).

<u>Johnson and Johnson's Cooperative Learning Implementation Model - Evidence Based</u>

Cooperative learning is one of the most widely adopted innovations in engineering education. Central to the cooperative learning model are five research-based key elements (Smith, Johnson and Johnson, 1981; Johnson, Johnson and Smith, 1991):

1. positive interdependence
2. individual accountability
3. face-to-face promotive interaction
4. teamwork skills
5. group processing

At the heart of the cooperative learning model is positive interdependence which is based on Lewin's social interdependence theory.

Cooperative learning has received fairly widespread adoption by engineering faculty, in part because of the solid foundation of theory, empirical research evidence, and practical examples; as well as an implementation model summarized below. Johnson, Johnson and Smith have extensive experience helping faculty implement cooperative learning, especially in helping them 1) promote an attitude of experimentation, 2) synthesize common goals, and 3) create collegial support networks. The implementation model is based on two major synthesis projects on enhancing human performance conducted at the National Research Council (NRC) (Druckman & Bjork, 1999; 1994). Both these projects emphasized training. Based on a review of this NRC work and work with faculty development in cooperative learning, that is, the use of high-performance student teams, Johnson, Johnson & Smith found that effective training practices require (Johnson & Johnson, 1994, 1995; Johnson, Johnson & Smith, 1998; Smith, 2000, 2004):

1. Focus on teams. The use of teams in training promotes a variety of outcomes. Not only will the proficiency of individual participants be increased, so will team productivity. While participants work together to complete the training, positive and supportive relationships will tend to develop, even among teachers from different ethnic, cultural, language, social class, ability, and gender groups. Working together and developing positive also contributes to increased psychological health, self-esteem, and social competencies. Finally, completing a training program together can change a team's norms, roles, communication patterns, and decision-making procedures.

2. Have the participating participants actively use the procedures through micro-teaching and guided practice. In mastering procedural skills, listening and watching are

ineffective compared with doing.

3. Distribute training across a number of sessions. Typically, massing training sessions will result in better performance in the short term (during the training) than will the spacing of practice, but much poorer performance in the long term.

4. Emphasize conceptual understanding of the nature of the learning and the basic elements that make it work. Emphasizing conceptual understanding increases retention, transfer, and long-term implementation.

5. Have participants overlearn a basic set of procedures. The more participants plan and implement a variety of implication and application ideas over a period of time the better.

6. Make the training challenging. Training can be made more challenging by increasing the cognitive demands required for understanding project management concepts and principles through such procedures as having participants practice under varied conditions and sequences. Generally, the more cognitive processing required, the greater the retention and transfer.

David and Roger Johnson of the Cooperative Learning Center at the University of Minnesota recommend a three-year plan to develop faculty leadership in the use of cooperative learning (Johnson and Johnson, 1994). They suggest starting with an awareness session so that all faculty gain a common understanding of cooperative learning. As a result of the awareness session, interested faculty are asked to volunteer to participate in a multi-year, long-term training program. Their experience indicates that three rules of organizational change are relevant here. The first is, *Start with your strength*; that is, start with the most interested and dedicated faculty. The second is, *Load your resources for the success of initial efforts*. The initial faculty should be provided with the necessary resources to implement cooperative learning successfully. The third is, *Build an in-house demonstration project*. The initial faculty trained become demonstration sites for other faculty who wish to see cooperative learning in action.

Implications for supporting change

The cooperative learning implementation model based on the National Research Council synthesis work as well as the practical experience of cooperative learning leaders provides an excellent base and starting place for the development of the change in engineering education.

<u>Seymour's Analysis of Change - Theories held by people / embodied in artifacts</u>

Seymour (2001) explored the theories of change present in SMET education reform. In this empirical and inductive work, Seymour worked as an ethnographer and analyzed discussions and artifacts at a National Institute of Science Education conference. The theories that she identified are presented in Table 3. These theories are not so much about what is predicted to be a best strategy, but instead about what people themselves believe to be a good strategy. Further research could be used to validate which of these strategies most often leads toward successful change.

Table 3. Theories of change in STEM education (excerpts from Seymour 2001).

BottomUp & TopDown Theories of Change (including grassroots and network theories of change, and value-driven institutional leadership):
• *Bottom Up Theories* can be expressed as "reform across institutions or systems can be transmitted by the spread of grassroots action between individuals, campus groups, and networks" or "change can be built from small local beginnings, first by provoking and maintaining conversations that lead to local collaboration; then by making connections with collaborators on the same or other campuses," or "networks of such collaborations can build into a "critical mass" in favor of reform," or "good ideas, supported by convincing evidence of efficacy, will spread "naturally"—that, on learning about the success of particular initiatives, others will become convinced enough to try them" • *Top Down Theory* can be expressed as "system change within institutions requires unequivocal, high-level commitment to promote and reward classroom effectiveness and educational scholarship"
The Blueprint Model (progress depends on accessibility of proven models, practices, & assessment tool)
• *Blueprint Model* theory can be expressed as "Good intentions have to be channeled into actions that are already known to be effective. Time, effort and resources cannot be wasted on strategies that have not worked well in other comparable settings."
Alignment is Required at All Levels for Effective System Change
• *Alignment* theory can be expressed as "In order to make the curriculum more meaningful to students, faculty must articulate their learning goals, align their teaching and assessment strategies with these goals, and make students aware of their own learning processes" AND/OR "Learning is enhanced when all of the main elements in a class fit coherently and overtly together: class content and activities, lab work, assignments, the text, media and other resources" AND/OR "attempts to alter single elements in a complex social system will not be effective: each element must be aligned with the others for system changes to prevail"
Departmental Values are Key to Educational Improvements
• *Departmental Values* theory can be expressed as "Finding the means to leverage relevant shifts in departmental values and practices is the critical factor in determining whether the efforts of faculty—as individuals and groups—and of their institutions, will be able to improve the quality of SMET education, or achieve the wider goal of science-for-all"
Rebalancing the Departmental Rewards System to Reflect Respect for Teaching and Educational Scholarship
• *Rebalancing Rewards* theory can be expressed as "the fastest and most enduring way to promote a renewed emphasis on teaching in the service of learning in higher education is to restructure the faculty rewards system.
Evidence is a Necessary (if not Sufficient) Condition for Reform
• *Necessary Evidence* theory can be expressed as "it is necessary to provide clear and convincing evidence that innovative forms of teaching are as effective as, or more effective than, traditional approaches to teaching. It is not enough to claim that greater learning occurs; it must be demonstrated." AND/OR "it is necessary to provide clear and convincing evidence that all forms of teaching (whether "innovative" or "traditional") are effective in promoting student learning. It is not enough to claim that learning occurs; it must be demonstrated"
Change by Leverage from External Agencies
• *Leverage* theory can expressed as "change may be leveraged by agencies external to institutions." AND/OR "the time for development, implementation, and testing that agency grants provide, plus the prestige of such awards, will increase the chances that innovation will take root in the host institutions beyond the end of funding"]

It is relatively easy to see these theoretical stances in the context of initiatives in engineering education. For example, the work on cooperative learning, discussed in the previous section, is suggestive of the "blueprint" theory, at least in the sense that cooperative learning provides a blueprint that others can explore. The existence of the NSF departmental reform grants seems consistent with the theory of "change by leverage from external agencies." The availability of faculty teaching support at campus teaching centers suggests the theory of "bottom-up change," that the individuals engaged in the consultation have the ability to change their own teaching and possibly others.

One aspect of the power of Seymour's contribution is having the theories so readily contrasted with each other. For example, the bottom-up theory of change is not only understandable from its title, but also from the contrast with the top-down, blueprint, and other theories. Additionally, Seymour's contribution, which is about the conditions under which change occurs, is clearly different from a stage approach such as Palmer's, which characterizes the process over time by which change occurs. It is interesting to consider that Seymour's proposed theories may have applicability conditions. For example, there may be contexts in which a blueprint model is the most effective approach to change and other contexts in which the departmental reward system is truly the most significant key. Such a proposition could be tested empirically.

Implications for supporting change.

Seymour's work has a variety of implications for supporting and promoting change in engineering education. For example, each of the theories suggests strategies that reformers can choose among when deciding how to approach change. Further, a reformer might pursue multiple strategies concurrently, in order to maximize the likelihood of successful change. Seymour's work also highlights that possibility that various reformers will have discrepant models. As a result, it may be difficult for reformers to agree on how to proceed. At minimum, it seems important that reformers come to a shared understanding in order to take action.

Backing up a bit – how are these models related to each other?

In the previous sections, we explored three threads of scholarship on change relevant to engineering education. These threads are different in a number of respects. For example, they focus on different aspects of change – the process or stages involved, the identification of principles to guide change, and the articulation of underlying theories of change held by educators themselves. The threads also seem different in terms of specificity. While the Parker and Seymour models are generalized accounts of change, the Johnson and Johnson model focuses on principles for achieving change in a specific context – cooperative learning.

Case Study: the Academic Pathways Study in the Center for the Advancement of Engineering Education

So far in this paper we have listed a series of change models, described three in depth, and briefly discussed some of the complexities of this work. In this section we would like to describe a new center funded by NSF that focuses on engineering education briefly and describe how we are conceptualizing our approach to change.

The Center for the Advancement of Engineering Education is a center that is funded for five years by the National Science Foundation. It is a collaborative effort involving colleagues from colleges of engineering and education, and among five institutions: Colorado School of Mines, Howard University, Stanford University, University of Minnesota and University of Washington. We are combining our forces in a three-pronged approach to focus on a Scholarship on Learning Engineering, a Scholarship on Teaching Engineering, and a series of Engineering Education Institutes. These three elements of our work are briefly described in Table 4.

Table 4. Overview of the Center for the Advancement of Engineering Education (CAEE)

CAEE Goals are:
• Understand and enhance the engineering student learning experience • Integrate the needs of diverse faculty and diverse students into engineering education • Strengthen the engineering education research base • Expand the community of leaders in engineering education • Promote effective teaching for current and future faculty
Scholarship on Learning Engineering
Our goal is to gain significant insight into the learning of engineering across diverse student populations and environments. To that end we will conduct in-depth longitudinal studies of engineering students' educational experiences and transitions to the workplace. The emphasis will be on the challenges students face and how they handle those challenges. These longitudinal studies at Colorado School of Mines, Howard University, Stanford University and University of Washington will be followed up with surveys of student experiences at a broader set of collaborating institutions. We will also conduct a set of "targeted studies" to investigate core components of engineering knowledge and practice.
Scholarship of Teaching Engineering
Our goal is to help the engineering education community provide effective educational experiences for all students. We will emphasize the role of decision making in teaching, and will 1) conduct studies of faculty decision making using multiple methodologies, and 2) work with graduate students to support their teaching decision making through the Engineering Teaching Portfolio Program (ETPP). The ETPP will provide resources and activities for current and future engineering educators to document, review, and revise their teaching decisions.
Engineering Education Institutes
Our goal is to foster a diverse cadre of leaders and change-agents in engineering education who can conduct high impact research. We will design and conduct three Engineering Education Institutes (at the University of Washington, Stanford University and Howard University) where engineering faculty and graduate students will 1) learn research methods, 2) define and conduct research studies linked to the ongoing scholarship in the Center, 3) create resources for dissemination, and 4) refine leadership skills.

In the Scholarship on Learning Engineering program we are developing an understanding of how students come to engineering and what leads them to leave or stay. Halpern (2002) advocates that reform efforts should embrace what we know about how people think, how they learn, and how they remember. We agree and these questions are central to our research efforts. In the Scholarship on Teaching program we are focusing on faculty decision making. Understanding faculty decision making seems to be central to an effective approach to change. We also focus on preparing graduate students (future faculty) for an entry into the professorate that is informed about learning and teaching. Finally, in the Engineering Education Institutes program we are preparing faculty to conduct systematic research in engineering education. These faculty will then join the community of educators who are embracing change.

In the work of our center we are endeavoring to create a rigorous empirical foundation to describe learning and teaching practices in the engineering education community and use the resulting insights to create conversations among change agents that will result in change at multiple levels. With the list of things we are doing, there are opportunities to affect change at multiple places in the engineering education system.

Our work acknowledges the complexities of the system within which we are working. To illustrate, we will briefly describe the Academic Pathways Study (APS) – one aspect of the Scholarship on Learning. The APS study is an in-depth longitudinal study at the Colorado School of Mines, Howard University, Stanford University, and the University of Washington in which we are studying the undergraduate student experience from the freshman to the junior year using multiple research methods. Our current plan is to follow up with a survey study of a broader set of universities. We anticipate being able to tell a rich story about the factors that contribute to successful and unsuccessful navigation of the engineering experience on these campuses.

At the beginning of this study, in a brainstorming session we asked the researchers the following question "Through the Academic Pathways Study we are creating __1__ for __2__ to enable __3__." The answers that were generated are displayed in Table 5. Any combination of the answers to the three blanks may lead to different emphasis on data collected, analyses to be performed, dissemination audiences to be reached, etc. The responses demonstrate the richness of the possible opportunities, the complexities of the system we are engaging with and the necessity for our team to choose among the possible options. The effectiveness of our choice among the options is clearly dependent on the contextual factors that are in place in the location of study. The institutions involved in the APS study are very different (in terms of size of university, number and types of departments, student body, student support organizations, public/private, etc.). Our plan is to choose those aspects of various change models that make most sense for the participating universities. One anticipated output of the center will be an elaboration not only of research findings (about student learning or faculty teaching) but also an elaboration of what elements of the system will foster the most effective change in varying types of institutions.

Table 5. The complex goals of CAEE's Academic Pathways Study. Study team members' responses to a 'fill in the blank' statement about the goals of the study.

"Through the Academic Pathways Study we are creating __1__ for __2__ to enable __3__."

1: Foundation, database, pictures, stories, opportunities, expectations, revelations, problems, questions, relationships, lessons learned, pathways, resources, ideas, accounts, descriptors, processes, definitions, scenarios, grounded theory, research models, empirical claims, tools, instruments, quick read, publication series on engineering education, quality control model for engineering education, confidence, legacy, learning career guide for students, misconceptions, future research directions, roadmap, territory, "how people learn engineering," forum, venue,

	place, context.
2:	Us, U.S., students, engineers, teachers, policy makers, NSF, educational programs, education institutions, industry, learning sciences, engineering faculty, faculty, potential students, guidance consolers, teachers in the U.S., U.S. president X, employers, NRC, NAE, European community, ASEE, professional societies ASME IEEE+, Educational technology, parents, globe, mentors (coaches), community, administrators, legislature, the electorate, educational foundations, higher education community, corporate presidents, community colleges, student organizations.
3:	Better learning, change, better society, informed electorate, broadly thinking engineers, new research directions, better teaching, better mentoring, better retention, better recruiting, clearer pathways, better self-understanding/awareness, knowledge base, awareness of diversity in many senses, multiple pathways, autonomous learning, enable learning how to be a good student, better policy, diversity in pedagogical practices, success for all, concept based learning, better educational support, improved self-efficacy/confidence, better engineering.

Concluding Remarks – Engineering an Approach to Change within CAEE

In this paper, we identified a number references that grapple with the issue of change in engineering education, and then discussed three of these references in greater depth. We then introduced a case study showing the complexities involved when exploring an approach to change in the context of a multi-institutional center. We are excited about this opportunity for us to jointly explore how to engineer an approach to change that is successful.

Another approach to change that is central to CAEE's mission is to study the process of change in CAEE. Poole, Van de Ven, Dooley and Holmes (2000) list the following criteria that adequate research on change and development processes should satisfy:

1. Explanations of change and development should incorporate all types of forces that influence these processes.
2. Explanations of change and development should incorporate generative mechanisms suitable for organizational contexts.
3. Research designs should capture data directly from the process through which development and change occurs.
4. Analytical methods should be able (a) to discover patterns in complex data and (b) to evaluate process explanations (pp. 4-5).

Finally, we think change should be treated as a scholarly act, as described by Judith Ramaley (2000) in the following quote:

> Achieving transformational change is a scholarly challenge best dealt with by practicing public scholarship, which is modeled by the leader and encouraged in other members of the campus community. Like all good scholarly work, good decision making by campus leadership begins with a base of scholarly knowledge generated and validated by higher education researchers, (page 75).

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