Examining a Novel Theory-to-practice Effort in Engineering Education through Multiple Theoretical Lenses of Systems and Change

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Abstract

In the past, the engineering education community has focused primarily on developing evidence-based best practices and fundamental theories of teaching and learning. An emerging focus, embodied in initiatives like the National Science Foundation’s (NSF) Revolutionizing Engineering Departments (RED) program, is on achieving systemic, sustainable, and scalable change, that is, the translation of theory to impact practice. Current models for engineering education units within universities have achieved goals to develop fundamental theory, making engineering education into a viable discipline. Alternative institutional models for engineering education are beginning to emerge that explore new avenues for achieving widespread, transformational impacts on educational practice. This paper describes a novel, next generation approach to translating theory to practice, and transforming an institutional culture through an integrated focus on building community and shared capacity around the scholarship of teaching and learning (SOTL) and educational research in a college of engineering.

When organizing a departmental or programmatic effort, logistical decisions can dominate and obscure the underlying organizing theory for the effort. Consistent with NSF’s calls for a greater understanding of theories of change, we connect the explicit and implicit organizing philosophies underpinning the innovative approach to enacted institutional plans and approaches. We draw on Henderson’s theoretical models of Institutional Change in higher education to clarify the chosen approach to transformation. We also draw on a complex systems perspective as a guiding philosophy to conceptualize change in the interconnected human, institutional, and social structures of our engineering college, and on boundary spanning to address the ways that communication across knowledge domains can be enacted and supported. The anthropologically inspired methodology explores institutional artifacts, structure, and guiding philosophies for their explicitly stated or implicitly enacted theories. As a collaboration between insiders (founders and longtime participants) and relative outsiders (a new participant), the innovative approach could be both described from experience and examined anew, and could explore both planned intentions and enacted realities.

Guiding principles, made explicit in PROGRAM founding documents and written reflections of organizers, include “plant a lot of seeds” and “people are the drivers of change.” An organizing structure includes administrative and faculty roles with dual focuses on developing research and translating to practice. Several opportunities for engagement between researchers and
practitioners are structured as regular events and forums. We connect the guiding theories to specific aspects of PROGRAM to clarify the purpose and implicit assumptions embedded inside institutional practices. For example, the events and forums can be understood as a form of boundary spanning, while the underlying goal of investing in people is consistent with Henderson’s “developing reflective practitioners” model for institutional change. We highlight PROGRAM’s approach to engineering educational transformation, substantiated by guiding theories. In so doing, we hope to provide greater insight into one approach, show contrasts with other approaches, and suggest a parallel theoretical clarification as a generative activity for other efforts at institutional change.

Introduction

What is the role of theory in of engineering education research and practice? What is the theory of change that underpins the discipline itself? As a relatively new field of study, the answers to these questions are still very much in flux (Jesiek, Newswander, & Borrego, 2009).

Early proponents of the discipline argued that published descriptions of ad hoc improvements to teaching and learning in engineering were lacking in rigor, which limited both their validity and transferability to other settings (Borrego, 2007; Shuman et al., 2002). According to these pioneers, the purpose of engineering education research was to bring rigor to the inquiry process which would, in turn, result in the development of evidence-based practices that practitioners could confidently draw on to transform engineering education (Streveler & Smith, 2006). This expected widespread adoption of evidence-based practices, however, has not yet occurred (Borrego, Froyd, & Hall, 2010; Borrego & Henderson, 2014). One assumption that underpinned these efforts was the transformative potential of integrating theory into engineering education research and practice, i.e., through the use of theoretical frameworks in research, and applied theories in practice (Felder & Hadgraft, 2013). The perceived multiplier effects of bringing theory into engineering education held the promise of high impact and generalizable solutions to intractable problems within traditional models of instruction. But even the most basic theories, such as constructivist theories of active learning, have, at least according to the dominant discourse, thus far failed to significantly “move the dial” (Besterfield-Sacre, Cox, Borrego, Beddoes, & Zhu, 2014; Kinoshita, Knight, & Gibbes, 2017; Nguyen et al., 2017).

These disappointments could have led to despair and atrophy in the field, but instead new directions are emerging. In 2014 the National Science Foundation released the first REvolutionizing engineering and computer science Departments (RED) solicitation. The goal of this program was to support revolutionary, not incremental, change. Competitive proposals had to “tear down the walls” of existing departments and construct in their place “a culture supportive of holistic professional formation” (NSF, 2016). The RED program reflects a shift in the discourse towards pursuing transformative impact on educational practice. Most recently, the
discourse has shifted to a focus on characterizing and evaluating that impact in the form of bridging the research-to-practice, or theory-to-practice, gap. In NSF review panels facilitated by the Division of Engineering Education and Centers (EEC), broader impacts are now discussed before intellectual merit, the implication being that broader impacts are just as, if not more important than, intellectual merit. Against the backdrop of these shifts in the discourse, the enterprise of engineering education has flourished - large schools and departments of engineering education have grown larger, and smaller centers and groups have been established across the country. And yet, the challenge of bridging the gap between theory- and research-to-practice continues to galvanize further innovations in the discipline.

In this paper, we describe our response to these challenges in the form of a recently established cross-disciplinary unit - the PROGRAM at the UNIVERSITY. According to Henderson (2011, p. 952), “research communities that study and enact change are largely isolated from one-another.” Our institute seeks to integrate these two perspectives with engineering education researchers and practitioners working side by side. Broadly speaking, our institutional model shifts the focus from what we identify as a deficit oriented approach to educational change to a dialogic and strengths perspective. Put simply, instead of focusing on instructors’ problems or deficits, a strengths perspective works with instructors’ abilities, talents, and resources to develop shared capacity. More specifically, our institutional model combines insights from complex systems theory, boundary spanning, as well as the literature on reflective practice, action research, and learning organizations. The purpose of this paper is to unpack these theories, and to map them onto the organization, programming, and lived experience of our institute. In doing so, our goal is to both become more aware of and reflective about our own processes, as well as share some preliminary insights and outcomes from our efforts.

Emerging Theories of Change in Engineering Education

Growing interest in transforming traditional models of engineering education has sparked initiatives on many fronts which seek to radically transform institutional cultures and teaching practices. Past efforts for facilitating change have been pursued through a range of approaches at multiple scales of organization from the individual, departmental, institutional, and whole education system level. It follows that the theoretical grounding of change strategies found in the literature are as varied and complex. Some examples of theories that have guided previous institutional change efforts include: expectancy value theory applied to understanding factors that influence faculty motivation (Finelli, Daly, & Richardson, 2014), Wlodkowski’s theory of adult learner motivation as a framework for designing instructional development programs (Felder, Brent, & Prince, 2011), the diffusion of innovations to understand propagation of teaching strategies (Borrego et al., 2010), the fidelity of implementation to track and measure diffusion research-based instructional strategies (Borrego, Cutler, Prince, Henderson, & Froyd, 2013), and the role of collaborative reflection in shaping teaching approaches (McKenna, Yalvac, & Light, 2009).
Henderson’s framework of the four primary change strategies used in STEM education offers a way to categorize change theories and efforts such as those referenced above (Henderson, Beach, & Finkelstein, 2011). This framework categorizes change strategies using two criteria: the primary aspect of the system the change strategy seeks to change (individuals versus environments and structures) and the extent to which the intended outcome of the change strategy is already known (prescribed versus emergent). The four categories presented in this framework are Disseminating Curriculum and Pedagogy (individual/prescribed), Developing Reflective Teachers (individual/emergent), Enacting Policy (environment and structure/prescribed), and Developing Shared Vision (environment and structure/emergent). Disseminating Curriculum and Pedagogy describes change processes that seek to inform individuals about new teaching conceptions, practices, and materials in hopes of encouraging their use within the classroom. Developing Reflective Teachers involves supporting individuals to develop and reflect on teaching conceptions and practices. Enacting Policy involves altering the organizational ecology of a department or college such that new teaching conceptions and practices are pursued. Developing Shared Vision seeks to engage stakeholders in collectively developing new environmental features that encourage new teaching conceptions and/or practices.

Henderson et al.’s framework does not imply that all four change strategies are equally effective. In fact, Henderson identified two approaches - testing “best practice” curricular materials and making these materials available to other faculty and “top down” policy-making meant to influence instructional practices - as ineffective change strategies in STEM education (Henderson et al., 2011). Additionally, their review found that effective change strategies are those that are aligned with or seek to change beliefs of the individuals involved, involve long-term interventions, and recognize colleges and universities as complex systems (Henderson et al., 2011).

For the purposes of this paper, the remaining parts of this section further describe two aspects of Henderson’s model that are most relevant to PROGRAM, and which align with the emergent strategies of Developing Reflective Teachers and Developing Shared Vision. In addition, we expand on two areas of literature, systems thinking philosophy and boundary spanning, which further inform these change strategies, and have emerged as particularly salient in our experiences with PROGRAM.

Both the Developing Reflective Teachers and Developing Shared Vision categories approach the outcomes of instructional change as an emergent aspect of the change process. Developing Reflective Teachers involves engaging and supporting faculty to reflect on their teaching in order to bring about changes in their instructional practices based on their own best judgement. Put another way, this approach enables instructors to improve their teaching by supporting them in changing aspects of their teaching that they themselves are interested in. Henderson et al.’s four category model has been expanded on by Borrego and Henderson (Borrego & Henderson, 2014) to make explicit the goals, assumptions, and underlying logic of each strategy category. Two examples of developing reflective teachers given in Borrego & Henderson (2014) include scholarship of teaching and learning, and faculty learning communities. Developing Shared
Vision involves supporting and creating new environmental conditions that lead to the emergence of new teaching innovations. Change agents aid in developing shared vision by engaging individuals with diverse perspectives towards the development of new organizational knowledge. Henderson et al. (2011) assert that the primary assumption implicit in emergent change strategies is that “important knowledge relevant to a change outcome exists in individuals throughout the system. Therefore, a variety of stakeholders should be involved in determining the intended outcomes” (p. 960). Emergence is a concept that plays a central role in understanding complex systems, which exhibit properties and behaviors that cannot be easily understood solely in terms of the parts that comprise them. Henderson et al.’s discussion of emergence reaffirms the call for complex system approaches for facilitating transformation in engineering education, which are abundant but not currently well developed. We contend that systems thinking philosophy, along with boundary spanning, provide useful frameworks for furthering the theoretical development of emergent change strategies as well as aiding in our description of our novel approach to change.

Systems thinking is characterized by an understanding of emergent wholes as complex systems, which have properties that cannot be understood solely in terms of the parts which make them up. Complex systems are irreducible and holistic; having properties that continue to endure even as the components of the system are replaced over time. The College of Engineering at UNIVERSITY can be conceived of as a complex system with its own set of values, structures, hierarchies, resources, and relationships, which interact together to influence the emergent characteristics of the system as a whole. Systems thinking philosophy, exemplified by the work of Donella Meadows (2009) and Ervin Laszlo (1975, 1996) provide useful frameworks for making general statements about complex systems such as a college of engineering. Donella Meadows observes that well-functioning systems typically have at least one of three characteristics: resilience, self-organization, and hierarchy.

The first system characteristic discussed is resilience, which can be thought of as the ability of a system to dynamically adapt to changes and persist through variable environments. Resilience is built into systems when multiple feedback loops provide redundant mechanisms for ensuring a system continues to function. Meadows points to ecosystems as a remarkably resilient example of a complex system “…with multiple species holding each other in check, moving around in space, multiplying or declining over time in response to weather and the availability of nutrients and the impacts of human activities. Populations and ecosystems also have the ability to “learn” and evolve through their incredibly rich genetic variability. They can, given enough time come up with whole new systems to take advantage of changing opportunities for life support” (2009, p. 77). The diversity that underpins the resilience of functional systems also provides the basis for which systems can further learn, complexify and evolve new structures. This property of self-organization describes the ability of systems to structure themselves in unpredictable ways. Self-organization can produce whole new system structures and innovations, however it “requires freedom and experimentation, and a certain amount of disorder” (Meadows, 2009, p. 80). The final characteristic of functional systems discussed by meadows is hierarchy, a common structure that is often generated in self-organizing systems. Hierarchies can offer numerous benefits, but can also potentially influence a system to behave in undesirable ways. When hierarchies are
functional, they provide a system with stability, resilience and function to establish and maintain information flows so that each part of the system has relevant information without being overwhelmed. Hierarchies, can however, also be the source of system malfunctions. These malfunctions can occur when a subsystems goals come to dominate the overall goal of the whole system, known as suboptimization; or when system control is overly centralized to the point of restricting subsystems from performing their function. Hierarchies remain functional when “the original purpose of a hierarchy is always to help its originating subsystems do their jobs better” (Meadows, 2009, p. 84). By understanding and recognizing these characteristics of highly functional systems we may act to promote system characteristics that generate sustainable transformation of our college. It is worth noting that Meadows work on “leverage points” – a list of 12 places to intervene in a system also provides valuable insight to understanding change within complex systems, however this extensive list is difficult to operationalize for the purpose of this paper.

In recognition that the positive outcomes of emergent strategies are driven by both the implicit and explicit knowledge held by individuals throughout the system (Henderson et al., 2011), we also find that the strategies and insights from boundary spanning literature offer salient contributions and practical strategies developing systematic change strategies. The terms “boundary spanner” and “knowledge broker” broadly refer to individuals who perform the many roles needed to facilitate the gathering, transfer, translation, and transformation of knowledge between individuals and groups within or across organizations separated by some boundary (Carlile, 2004). When individuals specialize in different fields of practice, they develop a unique language, identity, and system of knowledge common to other practitioners inside their field but often inaccessible to those outside of it. Boundaries between actors naturally emerge due to these differences which potentially leads to conflict and breakdown of coordination of group activity. Such conflicts can arise from differences in culture, language, domain of knowledge, motivation, identity, profession, position within a hierarchy, and organizational loyalty. Paradoxically, these same boundaries are also vital to the innovation process. Exposure to diverse systems of knowledge lead to the generation of new and better ideas through the combination and synthesis of existing knowledge from diverse domains. As such, these boundaries simultaneously present both opportunities and challenges for the success of collaborative ventures because they function both as a source and barrier to innovation (Carlile, 2002). This trade-off between knowledge boundaries’ role in innovation and coordination has been described as the “idea problem” and the “action problem” (Obstfeld, 2005). The role of the boundary spanner is often to minimize the barriers present in coordination while seeking to effectively utilize diverse systems of knowledge present in such networks.

Boundary spanners often use boundary objects to facilitate knowledge management across a boundary. A boundary object is any object or artifact that is shared by actors across different knowledge domains, which is used to create shared meaning so that knowledge can be made explicit, differences and interdependencies can be understood and managed, and ultimately new knowledge can be generated. Carlile characterizes an effective boundary object as one that “establishes a shared syntax or language for individuals to represent their knowledge, provides a concrete means for individuals to specify and learn about their differences and dependencies
across a given boundary, and facilitates a process where individuals can jointly transform their knowledge” (Carlile, 2002). The use of boundary objects can also trigger the emergence of boundary-spanners-in-practice and the emergence of a new joint field of practice (Levina & Vaast, 2005). Boundary spanning strategies and the use of boundary objects provide a structure and process by which knowledge is managed across a boundary.

Methodology and Paper Organization

The anthropologically inspired methodology explores institutional artifacts, structure, and guiding philosophies for PROGRAM’s explicitly stated or implicitly enacted theories. As a collaboration between insiders (founders and long-time participants) and relative outsiders (a new participant), the innovative approach is described from experience and examined anew, and explores both planned intentions and enacted realities.

The following description of the Program comes from a combination of data sources:

- Institutional artifacts
  - PROGRAM Proposal. Founding document outlining the approach and philosophy for securing internal funding from the College of Engineering.
  - Artifacts were collected from key PROGRAM activities.
- Written reflection. Key founding faculty members were asked to reflect on the guiding principles they have had in mind while organizing PROGRAM.
- Interviews. Additional anecdotes and foundational history were uncovered through a recorded interview with key founding faculty members.
- Observation by all co-authors of PROGRAM operations and impacts on lived experiences of PROGRAM members.

The Program description has been organized into three parts. The first section, “The Plan” discusses the vision, principles, and structure laid out in foundational documents; the second, “The Enactment” discusses and characterizes the range of programming which encompasses PROGRAM activities; and the third, “The Experience” provides a view into the lived reality of the change process through the lens of an account of one faculty member’s participation in PROGRAM. Following each of these sections, a short analysis section discusses connections to the guiding theoretical frameworks related to institutional change, systems thinking, and boundary spanning. This analysis of the data from the theoretical perspective generates transferable insights into the dynamics of promoting institutional change.

Data: Programmatic Description

1. The Plan: Purpose, Principles, and Structure
The following original mission statement was written in the founding proposal document, which was developed to justify internal the internal UNIVERSITY College of Engineering investment in the infrastructure of PROGRAM.

“[The purpose of PROGRAM is to] Promote and sustain a culture of engineering education scholarship and innovation that reaches across all programs in the College of Engineering and promotes educational excellence and institutional diversity.”

The emphasis on culture, as a key element of the proposed initiative, was notably restated within an accompanying figure from the proposal (Figure 1). This figure conceptualizes a developing Engineering Education (ENED) culture as providing connections between educational research and pedagogical innovation and practice.

In addition, the following key principles were developed by PROGRAM organizers and designed to guide the enactment of these overarching goals. As part of the data collection for this paper, these principles (right column) were explicitly articulated by PROGRAM organizers as an empirical artifact, and were subsequently interpreted and reorganized into overarching categories (left column) by first author:

<table>
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<tr>
<th>Value People</th>
<th>People are the main resource and driver for change – work with them, connect them, support them with what they want to do.</th>
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<td>Allow shifting groups and open participation.</td>
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<td></td>
<td>Promote, support, and make visible the connections between people, interests, and initiative – since this is a shifting network this job is never done.</td>
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People in various roles have unique valuable contributions (e.g., professors, lecturers, staff, graduate and undergraduate students) we value this diversity, provide a space for those contributions, promote self-determined growth but don’t expect people to become like us.

Enable flexible contributions – people have a day job.

Value diverse outcomes – not just big, high-dollar, fundamental research. We see the health of our ecosystem in this diversity.

Enable the collective to fish rather than giving individuals fish.

We have to plant a lot of seeds – not all of them grow into what we expect but recognize all outcomes as valuable. Small projects might end without immediate outcome of follow-up larger project – but they will add to the larger fabric and provide the ‘fertile soil’ for other things to grow.

Table 1: Organizing Principles of PROGRAM

The values and goals are supported by a structure of current and future staff and faculty hires. This structure is the tangible enactment of the overarching purpose and the strategic vision for future efforts. While the diagrammed structure (Figure 2) shows a functional hierarchy with particular focuses on aspects and parts of the system, the roles also have some planned overlap between responsibilities.

Figure 2: PROGRAM Personnel Structure

1a. Analysis: Institutional Change within a Living Ecosystem

The section above outlines a plan for enacting institutional change in engineering education. The overarching mission is resonant with emergent institutional change approaches emphasized by Henderson et al. For instance, the emphasis on “culture” in the PROGRAM purpose suggests a level of a collective shared vision. On the other hand, the guiding principles make it clear that
organizers “don’t expect people to become like [them]”; in other words a narrowly defined shared vision is not a prerequisite to membership. The emphasis on valuing people’s individual growth suggests a resonance with approaches to Developing Reflective Practitioners (Henderson et al., 2011). Rather than embodying the individual and collective approaches in a dichotomous way, it seems that PROGRAM’s approach to institutional change blends the two approaches in a culture that recognizes and values diverse individual contributions. Indeed, “enable flexible contributions” and “value diverse contributions” are shared cultural values which are explicitly stated in the guiding principles.

As a plan for emergent institutional change, the above artifacts embody both structure and flexibility, with an explicit strategy for influence and intentional room for emergence. Thus, the central mission provides a guiding philosophy and a model for change, which is concretized into nuanced guiding principles and a structure of key actors’ roles. The principles explicitly shape the character of these roles, for instance, in many institutions the educational innovation and impact role might engage in top-down curricular dissemination similar to Henderson et al.’s Disseminating Curriculum and Pedagogy category. Instead, the new Associate Director will be guided by PROGRAM principles to take a more emergent and co-constructed approach to initiating innovation with faculty in the PROGRAM network and in the engineering department more broadly.

Underlying much of this plan is an understanding (demonstrated in the conceptual model) of PROGRAM and the engineering department as a living complex system, a human ecosystem. Understood as a human ecosystem, the PROGRAM network cannot be predicted or controlled, but can yet be characterized, understood, and influenced. As with many human ecosystems, the principles emphasize that the organizers are also within the system and enacting change from within. In order to promote change within this complex living system, there is an emphasis on working “with” people and not on them. The principle of valuing diverse contributions and the plan for empowering individuals by “enabl[ing] the collective to fish” provides opportunities for resilience and self-organization, which are noted as beneficial characteristics of functional complex systems. Resilience is also explicitly planned for by the structure with a level of redundancy between roles, and by the principle to “plant a lot of seeds” without demanding specific contributions and outcomes.

2. The Enactment: Programming Space for Conversation

The primary structured activities for the institute are found in PROGRAM documents and advertisements and outlined below:

- PROGRAM Forum, a large (30+ attendees) meeting that takes approximately once every two weeks, open to and advertised to all members of the Engineering faculty. Allows
opportunity for guest lectures, faculty workshops, and interactive discussions. The schedule of all Forum events to date is included in the Appendix.

- Incubator, a smaller (~10 attendees) weekly meeting of researchers and faculty interested in exploring and supporting collaborations that emerge from mutual interests and interactions in the meeting. Discussions include upcoming grant proposals, practitioners concerns, and in-progress paper submissions.
- CLUSTER research group (website), similar to other research groups around the College, a weekly meeting focused on research interests.
- Faculty Travel Fellowship, supports faculty to travel to engineering education research and other teaching and learning conferences, such as the annual ASEE conference and the Teaching Professor conference.
- Research Initiation Grant, internal mini grant program intended to support lecturers, tenure track faculty, instructors, and staff in initiating Scholarship of Teaching and Learning (SoTL) research and innovation efforts.
- Faculty Learning Community (FLC), an initiative run by the university-wide Center for Teaching and Learning (CTL), which supports groups of faculty to meet every two weeks during the semester for conversations on the scholarship of teaching and learning.

One prominent theme in the intended purpose of the programmatic structures and meetings is to provide a space for conversation. Organizers characterize the goals of these conversations in multiple ways. They describe a need to protect participants from other more results-focused elements of the institution, such as promotion and tenure requirements, or the large teaching loads of lecturers. They describe conversations as a catalyst for emergent collaborations and shared resources, such as a recent grant proposal collaboration on using virtual reality in statics instruction, which emerged out of conversation between a learning technology researcher and statics instructor. A recent Forum presentation provided a fishbowl example of the grant brainstorm to allow other engineering faculty insight into the process of developing this idea into a fundable research project.

Figure 3: Forum Fishbowl Social Reality Planning Whiteboard (October 11, 2017)
Other recent productive outcomes that have been catalyzed by these structures include winning internal grants from UNIVERSITY’s Office of Institutional Diversity, which connected to ongoing diversity recruitment efforts being explored by faculty. The grant outlet was introduced via the Incubator meeting, and multiple possible submissions were brainstormed during the meeting in order to complete two successful final submissions.

Organizers also describe the conversations as an opportunity for a more contextualized and bi-directional form for the dissemination and translation of research on engineering education into practice. Engineering education researchers describe a respect for the many years of practical teaching experience that lecturers and teaching faculty have, and that rather than telling them how to teach from the research as dissemination, having conversations about the mutual insights and confluence from research and practice seems a more respectful and productive form of translating research to practice.

In Fall 2016, a series of PROGRAM Forums explored the engineering faculty interests and resources. Faculty completed worksheets defining their Haves (what can you offer to others), Wants (what would help you advance your interest area), Plans (do you have any short or medium-term plans to advance your interest area), and Dreams (where would you like to take your interest area). An example of a completed faculty worksheet is shown in the next section. Faculty also did an interest clustering activity using sticky notes (Figure 4), and in the subsequent Forum broke out into interest groups to brainstorm collaborations (Figure 5).

![Figure 4: PROGRAM Forum interest clustering activity (September 7, 2016)](image-url)
This series of PROGRAM Forums was synthesized into a diagram representing the emerging interests of PROGRAM-associated faculty, shown below.
PROGRAM’s programming provides multiple opportunities for professors, lecturers, staff, graduate and undergraduate students, and engineering education faculty to foster new relationships, share interests and concerns about teaching and learning, and initiate collaborative ventures based around their collective shared interests. Across all programming, there is an explicitly stated goal of developing shared capacity around the scholarship of teaching and learning. The membership of PROGRAM draws from a diverse pool of engineering faculty, graduate students, and staff from all three schools across the entire college of engineering. PROGRAM members have a diversity of specialized knowledge and, in many cases, years of experience as teachers. Contrary to the otherwise existing norm in academic institutions, this expertise is strategically leveraged towards the development of shared capacity through the provision of multiple spaces for dialogue and collaboration and the co-creation of shared artifacts by participating members. The function of these spaces can also be understood through the lens of boundary spanning, in that individuals with diverse knowledge and expertise are brought together to jointly share and transform their understanding of teaching and learning. Thus, boundary spanning can be seen as a strategy for developing shared capacity, counteracting the intellectual and interactional siloing which can occur in educational institutions.

Portions of this programming are intentionally designed to provide redundant functionalities for boundary spanning conversation and developing shared capacity. For instance, the PROGRAM forum, Incubator, and the Faculty Learning Communities each provide a space for shared conversations and formulation of new collaborations. This range of programming embodies the complex systems thinking approach which provides for resiliency and exhibits self-organization. By providing redundancy, both in terms of scheduling (professors have other obligations at a variety of times) and scope (group size, expectations of contributions), PROGRAM members and interested faculty have the opportunity to engage with the institute on a flexible basis that best fits their individual interests, aspirations, and availability.

The boundary spanning conversations often revolve around jointly created artifacts, or boundary objects, which help to provide a shared medium through which knowledge and expertise can be made explicit, differences and interdependencies can be understood and managed, and knowledge can be transformed. Boundary objects aid in co-constructing the broader culture and direction of PROGRAM, and they lower the perception of hurdles faced when conducting fundamental engineering education research. Figure 6 shows two of the synthesized artifacts that were generated through faculty reflections, workshops and interest surveys collected at an early PROGRAM forum. These artifacts point towards the use of boundary objects for enabling reflection among members, coordinating the development of shared capacity, and delineating the dimensions of the complex system. Additionally, PROGRAM Forum was used to develop a collaborative grant proposal for using virtual reality to statics provides one example of the use of
boundary objects within PROGRAM programming. The project background, details, and a demonstration of the virtual reality software were given and then the group collectively discussed and generated a diagram of the many different dimensions by which this learning technology could be investigated empirically through fundamental engineering education research. In this case, the social reality diagram (Figure 3) which was co-created by the group, served to provide structure to the shared conversation, provided an explicit means of making existing knowledge known, and to elicit questions, concerns, or gaps in understanding.

3. The Experience: Seeing Growth in Faculty Members’ Journeys

Finally, we note that all of the planning and enactment that comprise PROGRAM as a whole are experienced and engaged in on the level of individual faculty members, staff, graduate students, undergraduate students, and other stakeholders. The following journey map highlights the path of one faculty contributor in particular.

![Figure 7: Journey map for individual faculty member growth and participation](image)

From a position in the college as a lecturer with initial interests in K-12 recruitment and diversity, this map tracks the individual’s trajectory from finding a home within PROGRAM, to participating as a more active contributor, to collaborating on emerging projects. Highlighted above the timeline of the journey map are some milestones of specific individual experience which intersect the shared programming events found in Forums and Incubator meetings. These can be seen as key influences on the faculty member’s journey. An example of an artifact from this individual faculty at the September 7 Forum is shown in Figure 8 below. The faculty also expressed this interest in the K-12 interest sticky notes in Figure 4 from the previous section.
Highlight below the timeline are the primary bodies which the faculty member influenced, and was influenced by, along the stages of his journey. These demonstrate the faculty member’s growing scope of influence, as new communities of influence are entered the existing communities and networks are maintained. Figure 9, below, shows one product towards the end of the trajectory, demonstrating influence on the university community: an excerpt of a successful internal UNIVERSITY grant proposal focused on K-12 diversity recruitment (~10K).
3a. Analysis: Individual Contributions to Community and Culture

The section on The Experience highlights an individual faculty member’s trajectory of growth in the PROGRAM community. It embodies elements of both individual growth and development, and the development in one’s participation and contribution to a shared whole. Thus it resonates again with Henderson’s two emergent approaches (reflective practitioners, shared vision), and with the broader characterization of PROGRAM as a shared culture which values diverse individual contributions. The journey of the faculty member shows growth into a role of contributing productively to the shared capacity of the whole.

This section also highlights the way in which a culture cannot only be planned for and programmed, but must be taken up and built by individual contributing members. Perhaps sometimes holistic characterizations of culture and institutional change can make some of the individual on-the-ground work seem mysterious or magical; either the culture works or it doesn’t. The growth in contribution of this faculty member to the PROGRAM community and culture shows in practice how culture can be created, individually and collectively, by its participants.

Due to the collection of institutional artifacts, much of this growth can actually be seen as developing out of organizers programming space for boundary spanning conversations. In this case, part of the strategy for planning boundary spanning conversations involved opportunities which coincided with individual goals and represented opportunities for shared capacity and
growth. The synergistic outcomes of these programmed events show that when those from disparate knowledge domains have strategically programmed meetings, the outcome can be more inspiration and productivity than could have been predicted or planned for from the resources of the constituent contributors alone.

**Discussion: Uses of Theory**

This study incorporated theories from social science, education, and philosophy to an ethnographic description of an institutional change effort in engineering education. This emphasis on social theory is consistent with recent innovations in scholarship on theories of change, trends in funding proposal requirements from bodies like the NSF, and the engineering education disciplinary movement of translating theory to practice. Nevertheless, the particular ways that these innovations and requirements for theory can be approached are myriad and sometimes seem opaque. From the process of this investigation, we have revealed at least three distinct uses for theory:

*Generative*

Theory can be used a priori, in order to conceive of and formulate the program. In this case, the key organizers were familiar with the writings and philosophies of complex systems and ecosystems, and these theories found direct application in the guiding principles and foundational documents of PROGRAM.

*Pragmatic*

Theory can also be used in situ, in the moment, in order to make organizational choices, develop appropriate programs, or measure impact. Theory was implicitly contained inside guiding principles, and could be drawn on to help guide the day-to-day logistical choices, which might otherwise become dominated by other concerns. For example, a complex systems perspective shifts the focus from the parts to the whole – from individual elements to the relationships between the elements. Pragmatically, this aspect of theory shifted the focus of PROGRAM programming from “outcomes,” such as adoption rates, research grants, and publications, to the building of relationships between PROGRAM members and shared capacity.

*Reflective*

Finally, theory can be used post hoc, to help understand, clarify, or communicate about the choices made and the structures already in place. In this case, theories of institutional change were a post hoc reflective tool, they helped participating co-authors clarify what is and is not resonant with PROGRAM. They also assist with communication and connection to others in the engineering education community, as a shared reference point from which to approach the detailed description.
Conclusion

We began this paper by suggesting a longstanding and ongoing discourse around the underlying purpose for the discipline of engineering education. Many voices in the discourse have suggested a variety of effective roles for the community: from researchers gathering evidence, to thought leaders developing theory, to disseminators of best practice, to revolutionaries inciting change. The role taken up by PROGRAM are in some ways humbler and more conversational than any of these options: the dialogic change-maker within a living ecosystem. This approach can build contextualized and embodied theory, and can lead to surprising productive outcomes. While we do not suggest that this exact approach will be embraced by existing programs perhaps already built on other foundations and philosophies, it may yet provide a new lens for conceptualizing a role for the discipline. Engineering education may benefit from considering its own opportunity for synergistic conversation spanning the boundaries of the knowledge domains of engineering and education, and its existence within the living ecosystem of the engineering discipline.

Reference:
Finelli, C. J., Daly, S. R., & Richardson, K. M. (2014). Bridging the Research-to-Practice Gap:


### Appendix: List of Forum events

<table>
<thead>
<tr>
<th>Date &amp; time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>September 7, 2016</td>
<td>Starting the conversation</td>
</tr>
<tr>
<td>September 30, 2016</td>
<td>Exploring shared interests</td>
</tr>
<tr>
<td>October 21, 2016</td>
<td>External speaker: Wendy Newstetter</td>
</tr>
<tr>
<td>February 2, 2017</td>
<td>Membership, overview, and planning</td>
</tr>
<tr>
<td>February 8, 2017</td>
<td>Interview “Seminar, doughnuts, and coffee” for engineering education faculty candidate</td>
</tr>
<tr>
<td>February 15, 2017</td>
<td>Interview “Seminar, doughnuts, and coffee” for engineering education faculty candidate</td>
</tr>
<tr>
<td>March 2, 2017</td>
<td>Interview “Seminar, doughnuts, and coffee” for engineering education faculty candidate</td>
</tr>
<tr>
<td>March 17, 2017</td>
<td>Distinguished lecture Bev Watford</td>
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<tr>
<td>April 3, 2017</td>
<td>Showcase of CENGR SOTL work</td>
</tr>
<tr>
<td>April 24, 2017</td>
<td>Discussion of virtual statics (start of fishbowl)</td>
</tr>
<tr>
<td>September 13, 2017</td>
<td>Welcome, plans for the semester, and report from PROGRAM members who attended the ASEE conference</td>
</tr>
<tr>
<td>October 11, 2017</td>
<td>Proposal development fishbowl 1: Defining the ‘social reality under investigation’ as a starting point for research planning</td>
</tr>
<tr>
<td>October 25, 2017</td>
<td>Engineering Education Showcase</td>
</tr>
<tr>
<td>November 15, 2017</td>
<td>Proposal development fishbowl 2: Structuring and writing an NSF engineering education proposal</td>
</tr>
<tr>
<td>November 29, 2017</td>
<td>Invited speaker End of year celebration</td>
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