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Riding the Wave of Change in Electrical and Computer Engineering

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Riding the Wave of Change in Electrical and Computer Engineering

Introduction

Electrical and computer engineering technologies have evolved into dynamic, complex systems that profoundly change the world we live in. Designing these systems requires not only technical knowledge and skills but also new ways of thinking and the development of social, professional and ethical responsibility. The Department of Electrical and Computer Engineering (ECE) at Iowa State University was awarded a National Science Foundation (NSF) grant in 2016 aimed at transforming curricula and practices to better respond to student, industry and society needs. This is being done through new structures for faculty collaboration and facilitated through departmental change processes. Ironically, an impetus behind this effort was a failed attempt at department-wide curricular reform. This failure led to the recognition of the need for more systemic change. Combined with department chair support, a diversity/inclusion initiative and the vision of a group of faculty, a project emerged from over two years of efforts.

The project uses a cross-functional, collaborative instructional model for course design and professional formation, called X-teams. X-teams are reshaping the core technical ECE curricula in the sophomore and junior years through pedagogical approaches that (a) promote design thinking, systems thinking, professional skills such as leadership, and inclusion; (b) contextualize course concepts; and (c) stimulate creative, socio-technical-minded development of ECE technologies. An X-team is comprised of ECE, design and engineering education faculty members, industry practitioner(s), context experts, instructional specialists, and graduate and/or undergraduate teaching assistants. X-teams use an iterative design thinking process and reflection to explore pedagogical strategies. X-teams are also serving as change agents for the rest of the department through communities of practice referred to as Y-circles.

Y-circles, comprised of X-team members, faculty, staff, and undergraduate and graduate students in the department, are contributing to an organizational culture that fosters and sustains innovations in engineering education through an agile framework that blends several documented change theories, including collaborative transformation, crucial conversations, and essential tension. Y-circles are engaging in a process of discovery and inquiry to bridge the engineering education research-to-practice gap. Research studies have been planned and will be conducted to answer questions to understand (1) how educators involved in X-teams use design thinking to create new pedagogical solutions; (2) how professional formation pedagogy in the middle years affects student professional ECE identity development as design thinkers; (3) how ECE students overcome barriers, make choices, and persist along their educational and career paths in the middle years; and (4) the effects of department structures, policies, and procedures on faculty attitudes, motivation and actions.

This paper describes the project, efforts that led up to the project, related work, and new approaches being developed and implemented.

Prior Efforts

In early 2013, with a charge from the department chair, the curriculum committee chair convened a task force to examine renovating the curriculum to reflect modern pedagogical practices. The task force benchmarked several nationally-recognized and innovative electrical/computer engineering programs, consulted the literature, and interacted with respected academicians about ECE education. The findings and recommendations of the task force focused on subject connectivity, hands-on design experiences, and flexibility in years 3-4 of the undergraduate program. An implementation plan was presented to the full faculty at the end of 2013, where it was thoroughly deliberated. Despite a positive vote to move forward, the curriculum committee chair soon encountered opposition from faculty before the implementation could be rolled out. Ultimately the reform effort stalled due to faculty concerns, revealing that deeper departmental transformation would be needed.

Despite the failed attempt, the department chair and a small group of faculty members remained interested in curriculum reform. Several of these faculty members had past success with a National Science Foundation (NSF) department-level reform pilot project, and thus attention turned to aligning efforts with NSF initiatives. In the coming year, the National Science Foundation announced the Revolutionizing Engineering Departments (RED) program as part of its professional formation of engineers (PFE) initiative. The RED program expects the deeper departmental change that was missing with the task force's implementation plan. After an unsuccessful proposal in the first round, the department was awarded a RED grant in 2016. This grant has provided the impetus for change through faculty collaboration and adoption of new mindsets and practices.

Motivation

A key focus emerged in this project for curriculum reform: student learning about the responsible development of ECE technologies, which considers individual and societal needs, and thus benefits from a design thinking approach. Howard Michel, past IEEE President, wrote: "It is critical that technical professionals not limit their role to creating the hardware, software, and interfaces. As a community, we should consider the responsible development of these technologies." [1] Such a vision for engineering is not new. In *Engineers for Change: Competing Visions of Technology in 1960s America*, Matthew Wisnioski presents the struggle of engineers and the profession to define their purpose and identity [2]. Charles Vest, former NAE President, wrote: "The social and intellectual unrest of the 1960s forced engineers, long the masters of how, to confront why. The struggle to establish a socio-technical framework for engineering, university curricula to imbue it, and a popular understanding of it remain largely unmet today." Wisnioski notes that "calls to make engineers more humane had a familiar ring" and elaborates on numerous efforts by ASEE, NAE, engineering schools, and others over the years. However, these efforts did not lead to systemic transformation, and even recent inspiring reform initiatives have encountered similar hurdles. Wisnioski observes (p. 185), "If faculty could not sustain reflective integration of 'social' and 'technical' knowledge, how could they expect future generations of engineers to do so?" He concludes that, "For engineers and those who teach their future ranks, revisiting the process of contextualization is important… because it insists our assumptions remain perpetually contested. That, after all, is the basis for change." (p. 198)

Design thinking offers a human-centered approach to transform both teaching and learning. It is a user-centered process that starts with user information, and facilitates designing artifacts that address real user needs and testing them with real users. It leverages collective expertise and establishes a shared language among team members while encouraging innovation through multiple explorations of the problem and solution spaces. There are phases that help navigate development from identifying a challenge to finding and building a solution, and each phase is meant to be iterative and cyclical. Design thinking is used by X-teams to explore pedagogical strategies. Design thinking is also a student learning outcome and skillset being integrated into selected ECE courses.

X-Teams: Collaborative Instructional Model

An X-team is a new strategy for managing courses and faculty based on a cross-functional, collaborative instructional model for course design and professional formation pedagogy (PFP), including design thinking. X-teams facilitate a new way of teaching needed for future scenarios of engineering education [3]. The X-team model is inspired by the work of Bess and associates [4]; he argued that the notion that college teachers are only lecturers has become greatly outdated in higher education since the instructional process is complex and demanding and requires a range of expertise that cannot be expected from any single individual [5]. Published in 2000, this portrayed a radical rethinking of teaching and academic work in which faculty members with different talents work together, support each other, and improve their practice. Bess identified seven major domains in the process of teaching: 1) Pedagogy, 2) Research, 3) Lecturing, 4) Leading discussions, 5) Mentoring, 6) Curricular and co-curricular integration, and 7) Assessment. He recommended a style of team teaching in which faculty form teams of specialists based on these domains of process knowledge. Aspects of the model are put into practice to varying extents when multiple faculty, staff and students are involved in the development and delivery of a course. For example, a learning management system specialist may work with an instructor to set up a tool to meet a specific pedagogical or assessment need. Increasingly today's flipped classrooms are involving process experts in course development, more commonly as a service orthogonal to a particular course. Features may be glimpsed in Stanford's ME218 Informal Learning Loops via coach and expert roles [6], and in recent programs from Harvard [7] and ASEE (I-Corps L) [8]. Course design and adoption of innovations are often constrained by the time and expertise of individual engineering faculty members, especially in relation to education research. The cross-functional, collaborative nature of an X-team is intended to alleviate some of the challenges.

The cross-functional composition of an X-team is illustrated in Figure 1. A team is comprised of two or three ECE faculty members including the primary instructor, at least one engineering education and/or design faculty member, at least one industry practitioner, context experts, instructional specialists, and graduate and/or undergraduate teaching assistants. Context experts are added as needed and may be ECE faculty or others. Instructional specialists are involved as needed to support the process of teaching, including effective inquiry and inclusive teaching. Team size may vary though a typical size is 6-10 members.

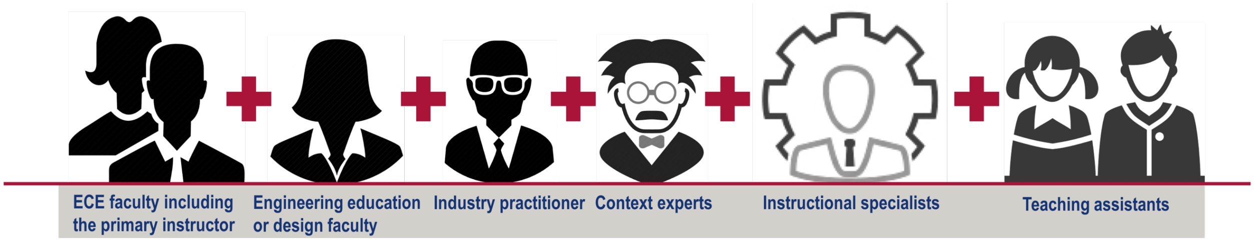

Figure 1. Sketch of X-team composition.

The goal of an X-team is to redesign a course to integrate PFP evidence-based practices, including the following strategies:

(a) promoting design thinking, systems thinking, professional skills such as leadership, and inclusion;

(b) contextualizing course concepts; and

(c) stimulating creative, socio-technical-minded development of ECE technologies for future smart systems, including security and privacy.

A team uses an iterative design thinking process and reflection to explore PFP strategies and integrate them into courses. As course redesign proceeds, a team gains more experience and collects more evidence, thus deepening and widening its knowledge base. A team supports an instructor in redesigning course materials and methods, with an emphasis on implementing PFP, effective inquiry and inclusive teaching in the classroom. Team members are also responsible for assessing student learning outcomes related to socio-technical and professional skills and for documenting and sharing their progress.

The X-team design thinking process includes generating a series of potential ways to deliver the topics (divergent thinking) and combining and synthesizing them into practical solutions for the course/curriculum (convergent thinking). The process draws on the diverse backgrounds of X-team members. As design thinking is supported by reflections at every stage, instructors must be open to change their perspectives regarding instructional materials and methods. The process is intended to engage faculty and other stakeholders and provide guidance to an X-team through the following steps:

1. Emergence: Faculty members and a select group of students and stakeholders gather to discuss the skills necessary for the students to succeed in the future.

2. Empathy: The group synthesizes the discussion to create a series of questions, such as, "how might we provide opportunities for learning about responsible development?"

3. Experimentation: The group generates a diverse range of ideas that include tools and processes that can be used in the curriculum.

4. Elaboration: The group prototypes several of these ideas about teaching and learning approaches and creates a vision for short and long term plans in order to continually build out this approach over time.

5. Exposition: Solutions are put into storyboards, illustrations, and vision statements for presenting to a broader audience.

6. Extension: Solutions are tested, and faculty take time to reflect on the experimentation and learn from each other.

Design thinking is not just for an X-team; it is for students too. The design thinking process being integrated into a course is intended to improve design learning by students and make a course more inclusive [9-18]. There are many approaches that define the characteristics of design thinking, such as tolerating ambiguity, viewing design as an inquiry, maintaining the vision for the big picture through systems thinking, handling decisions, and thinking as part of a team [9]. All of these characteristics require an important attribute: effective inquiry. Effective inquiry in design thinking is the systematic interplay between divergent and convergent thought processes. Traditional engineering instructional methods often focus on convergent approaches, in which deep reasoning questions lead to 'the' answer. Design thinking encompasses both.

X-teams are drawing on related work as a basis for ECE course redesign. For example, engineering education researchers have presented effective techniques for the second and third years of an engineering curriculum, including practices in ECE [19-21]. Studies have identified the importance and effectiveness of research-based instruction strategies in engineering and in particular for ECE disciplines [22-24]. Course redesign in this project is currently focusing on the following required core courses in the middle years:

- **Signals and Systems (EE 200-level):** signal manipulations, system properties, impulse response, convolution, Fourier series, Fourier transforms, sampling and reconstruction, modulation and demodulation.

- **Circuits (EE 300-level):** frequency domain characterization, transfer functions, sinusoidal steady state response, time domain circuit models, small signal analysis, feedback circuits, operational amplifiers, A/D and D/A converters.

- **Embedded Systems (CPE 200-level):** embedded C programming, interrupt handling, memory mapped I/O, elementary embedded design flow/methodology, timers.

- **Operating Systems (CPE 300-level):** processes, threads, synchronization between threads, process and thread scheduling, deadlocks, memory management, file systems, I/O systems.

These courses are prerequisites to many intermediate and advanced courses. X-teams are responsible for assessing student learning outcomes related to technical and professional skills and new mindsets in these pilot courses.

Y-Circles: Community of Practice

To achieve the change that is envisioned, X-teams cannot work in isolation. Communities of practice in the department that facilitate change and foster innovation are called Y-circles. Y denotes "why:" for example, engineers going from "how" to "why" to embrace a socio-technical context (Vest/Wisnioski); and educators asking "why" and using research to inform their decisions. Simon Sinek has stated in *Start with Wh*y [25], “People don’t buy what you do; they buy why you do it.” He underscored that “finding why is a process of discovery,” and “every company, organization or group with the ability to inspire starts with a person or small group of people who were inspired to do something bigger than themselves.” On this project, focusing on “why” supports:

- using research to inform instructional practices;
- stimulating a socio-technical context in engineering; and
- fostering motivation, inspiration, and innovation.

A Y-circle is vital to departmental change as a vehicle for implementing and blending processes based on collaborative transformation, crucial conversations [26], and essential tension [27]. A Y-circle is comprised of X-team members, department faculty members, postdocs, academic advisers and other interested staff, and undergraduate and graduate students. Participants include future X-team members who will learn from the experiences of current X-team members. X-teams share progress through Y-circles. Y-circle participants have the option to observe X-team activities. A Y-circle meeting is facilitated as a safe environment to openly discuss different views and find common ground.

Crucial conversations is one of the strategic change elements in the project and integral to Y-circles [26]. A crucial conversation is a discussion between two or more people where stakes are high, opinions vary, and emotions run strong. Dialogue is most effective when there is a shared pool of meaning. As individuals are exposed to more accurate and relevant information, they make better choices. A complementary change element is Kuhn’s so-called essential tension [27]. In the spirit of Kuhn’s theory, the project seeks a paradigm shift in the department in which some elements of prior beliefs and practices must be discarded or rearranged in order to assimilate new ideas and reach consensus. New ideas may be perceived as undermining traditional practices. It is important that the tension generated through open expressions of differing views builds toward as much shared agreement as possible (crucial conversations). Doubts, unanswered questions, and feelings of dissatisfaction among members of the department are expected through this process. Y-circle activities result in questioning old assumptions and creating newly shared meanings.

A Y-circle is formed with a specific goal in mind. Participants join based on their interests, involvement with an X-team, and invitations or requests from the department chair. A Y-circle may be about an X-team practice, teaching/learning issues of interest to the department, or change process findings. Three Y-circle topic areas have been introduced: responsible development, active learning, and inclusive environments. For example, in the area of active learning, there is interest in retrieval learning, or improving student retention of concepts and skills [28-30]. This is a perennial complaint by frustrated professors in the department, and often there is guesswork about reasons and solutions. There is lack of awareness of studies done, as well as lack of motivation to do things differently. In addition to the literature, there are experts on campus who serve as resources. This Y-circle topic is non-trivial and brings together various beliefs, emotions, assumptions, and evidence that must be confronted. It provides a testing ground for Y-circle procedures and a foundation for other topics.

We anticipate having two or three Y-circle topics each year, each allotted about three months and focusing on one of the three topic areas. We are encouraged by recent findings that even minimal exposure to active and inclusive learning topics can have noticeable positive impacts on faculty attitudes and behaviors. Each selected topic has a series of discussions, from introductory to more intensive. A topic is usually introduced in a departmental faculty/staff meeting in an introductory way by considering the “why” question. Department-specific information related to the topic is gathered as well. Institutional or professional resources related to the topic are also identified and shared, such as seminars and workshops provided by Iowa State’s Center for Excellence in Learning and Teaching (or other organizations such as WEPAN, NCWIT, IEEE, CIRTL, etc.). Faculty participation is encouraged and tracked. These Y-circle activities culminate in one or more facilitated meetings about the topic in the department involving various stakeholders.

Complementary to Y-circles, collaborative transformation is a strategic change process that will be used by the department starting next year. It is an established program successfully used by numerous departments on campus. It is the product of an NSF ADVANCE project and was designed to mirror back to faculty aspects of their own department that influence how positive their climate is and how effective their practices are. It systematically gathers and analyzes information about the culture of a department’s work environment. This information is then used to draft a report that is reviewed by the entire department, resulting in conversations and action plans. Diverse faculty views are obtained, and planned activities are tailored through the process. Following on essential tension and crucial conversations principles, the tension generated through open expressions of differing views is managed to reach shared agreement.

Research Studies

Research studies are being set up to investigate both faculty and student change. One study is examining how educators involved in X-teams use design thinking to create new pedagogical solutions. Using experience with design heuristics and heuristic theory, instructional heuristics practiced by X-teams will be explored and documented. The research design uses interviews and observations. Another study is examining how professional formation pedagogy in the middle years affects student professional ECE identity development as design thinkers. The concept of identity formation in engineering is quickly emerging as an important area of educational research. The research design is considering both micro- and macro-level influences as well as how ECE students overcome barriers, make choices, and persist along their educational and career paths in the middle years. The primary methods for data collection will be pre-interview questionnaires, semi-structured interviews, and document review. Lastly, another study is examining the effects of department structures, policies, and procedures on faculty attitudes, motivation and actions. For X-teams and Y-circles to succeed, ECE faculty must be motivated to change well-defined means of constructing and teaching discipline-specific information. In particular, the research design addresses whether participating in X-team and Y-circle processes results in more faculty satisfaction and engagement based on motivation theory. This study will also examine emergent change strategies.

Emergent Change

Emergent change is supported through X-teams, Y-circles and related project activities. This is described using a framework developed by Borrego and Henderson [22] based on four categories of change strategies [31], as shown in Figure 2. The four categories are based on two criteria: 1) the aspect of the system being changed, either individuals or environments/structures; and 2) the nature of the intended outcome, either prescribed or emergent.

<table>
<tr><td rowspan="4">Aspect of System</td><td>Individuals</td><td>I. Disseminating curriculum and pedagogy

Example change strategies:
• Diffusion (scattering)
• Implementation (training)

Role of change agent:
Inform/teach individuals about new concepts and practices and encourage their use.</td><td>II. Developing reflective teachers

Example change strategies:
• Scholarly teaching (self-reflection)
• Faculty learning community (community development)

Role of change agent:
Encourage/support individuals to develop new concepts and practices.</td></tr>
<tr><td rowspan="2">Environments</td><td>III. Enacting policy

Example change strategies:
• Quality assurance (accreditation)
• Organization development (leadership)

Role of change agent:
Enact new structures/procedures that require or encourage new practices.</td><td>IV. Developing shared vision

Example change strategies:
• Learning organizations (team learning)
• Complexity leadership (emergence)

Role of change agent:
Empower/support stakeholders to collectively develop new structures/procedures that facilitate new concepts and practices.</td></tr>
<tr><td>Prescribed</td><td>Emergent</td></tr>
<tr><td colspan="3">Intended Outcome</td></tr>
</table>

Figure 2. Emergent change framework (adapted from [22]).

Within this framework, project activities span all categories. Strategies within category I include training workshops for faculty and dissemination; and within category III, there are new programs and policies. X-teams and Y-circles have characteristics of the emergent change strategies in categories II and IV. In particular, an X-team or Y-circle guides emergent change by supporting features given in [22], such as:

- Encouraging faculty to use evidence to reflect on their teaching practices

- Bringing faculty together to support each other, expose one another to new views about teaching and learning, and hold one another accountable
- Changing faculty beliefs, motivation, practices or satisfaction with student learning (and other aspects of faculty work and the department work environment)
- Moving decision-making further from the top
- Investing in personal mastery, shared vision and group learning
- Encouraging group-level questioning and revision of mental models
- Disrupting tradition
- Encouraging innovation and creating new ideas through individual interactions
- Creating shared meaning

The aforementioned research study will focus on these types of effects in categories II and IV.

Conclusions

During the first year of the project, progress on X-teams and Y-circles has been oriented toward planning and input from stakeholders. In addition, project team members have participated in monthly teleconferences with other RED grantees, which helps to inform the development of these activities. These grantees include two other ECE departments (in addition to Iowa State), and we have been sharing information in several forums. In our work thus far, we have observed support for our efforts locally and through the RED community. Most faculty and staff in the department seem receptive to moving forward, some more anxious than others, although we recognize that we have not asked much of them yet. The department and college industrial advisory councils have also expressed interest and support. The coming year will present numerous opportunities and challenges for the project.

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