REINVENTING THE INSTRUCTIONAL AND DEPARTMENTAL ENTERPRISE (RIDE) TO ADVANCE THE PROFESSIONAL FORMATION OF ELECTRICAL AND COMPUTER ENGINEERS

PROJECT SUMMARY

The Department of Electrical and Computer Engineering (ECE) at Iowa State University, through the proposed project, Reinventing the Instructional and Departmental Enterprise (RIDE) to Advance the Professional Formation of Electrical and Computer Engineers, will make groundbreaking developments at the department level to enhance ECE student success on professional formation pathways into engineering careers and to engage faculty in professional formation pedagogy (PFP). This will be accomplished through collaborative, inquiry-driven processes that create and sustain new ways of thinking, interacting, teaching, learning and working. Change will be driven by RIDE’s revolutionary cross-functional, collaborative instructional model for course design and professional formation, called X-teams. The project will lead to (1) radically different department structures and practices for teaching and learning in core ECE courses (X-teams); (2) advances in scholarly teaching and education research department-wide (Y-circles); (3) ECE student professional formation and inclusion through contextual design thinking and professional skills development in the middle years (RIDE PFP); and (4) a more agile, less traditional, department able to respond to industry and society needs, sustain innovations, and serve as a model for ECE, computing and engineering departments across the country.

INTELLECTUAL MERIT

X-teams will reshape core technical ECE curricula in the middle years through novel and proven 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 for future smart systems, including security and privacy. Y-circles will engage in a process of discovery and inquiry to bridge the engineering education research-to-practice gap. Y-circles will contribute to an organizational culture that fosters and sustains innovation.

Research studies will answer questions to understand (1) how educators involved in X-teams use design thinking to create new pedagogical solutions; (2) how the RIDE PFP 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. The studies will inform and improve RIDE project activities, advance knowledge, and support adaptation by others.

BROADER IMPACTS

The broader impacts of this project intersect various areas, ranging from transformed infrastructures to socio-technical-minded workforce development. A primary broader impact focus of this project is broadening the participation of underrepresented groups in ECE, especially undergraduate women. Project activities emphasize inclusive teaching practices and learning experiences, professional engineering identity formation, and student persistence in the middle years. These are informed in part by an external assessment of diversity and inclusion in the department that highlighted strengths and barriers aligned with the literature. The department’s goal is to increase the percentage of undergraduate women enrolled in ECE majors from 8% (current) to 12% (national average for ECE), and longer term to 16% (college average for engineering). The RIDE project will complement several ongoing initiatives and partnerships to achieve increases. Project results will be disseminated through large national networks, such as the IEEE Early Career Faculty Development webinar series; the NSF Center for the Integration of Research, Teaching and Learning; and the National Alliance for Broader Impacts. In addition, participants in project activities, such as X-teams and Y-circles, will have access to mentoring throughout cycles of interactions, feedback and reflection.

REINVENTING THE INSTRUCTIONAL AND DEPARTMENTAL ENTERPRISE (RIDE) TO ADVANCE THE PROFESSIONAL FORMATION OF ELECTRICAL AND COMPUTER ENGINEERS

A. VISION FOR REVOLUTIONIZING THE DEPARTMENT

Whenever I go on a ride, I'm always thinking of what's wrong with the thing and how it can be improved. – Walt Disney

Times are changing, and so must engineers and the departments who train them for the world ahead. This is especially true in electrical and computer engineering (ECE) and in computing generally. ECE technologies have evolved from simple electronics and computing-based tools used by makers to solve specific problems, to complex electronics/computing-based systems used by humans to make work and life better. We are already seeing the future of smart systems in which interconnected electronics/computing devices are ubiquitous and perform tasks formerly done by humans as well as beyond human reach with minimal human intervention. The future with ECE technologies is just getting rolling and will fundamentally change the world we live in. Howard Michel, 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]

Before looking ahead, it is worth noting that this vision of change 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)

Thus, responsible development of ECE technologies ultimately comes back to responsible development of both students and faculty. The Department of Electrical and Computer Engineering at Iowa State University, through the proposed project, Reinventing the Instructional and Departmental Enterprise (RIDE) to Advance the Professional Formation of Electrical and Computer Engineers (PF/ECE), will accomplish this through collaborative, inquiry-driven processes that create and sustain new ways of thinking, interacting, teaching, learning and working. RIDE project activities will involve students, faculty and others in human-centered cycles of development in the PF/ECE ecosystem, not unlike the cycles that typify natural ecosystems. The cycles must, as Wisnioski advises, continuously challenge assumptions. These cycles of development and reinvention will have reinforcing effects that will collectively and systematically transform the department and the engineers it trains. These **cycles of change revolve around RIDE's proposed revolutionary cross-functional, collaborative instructional model for course design and professional formation, embodied in a new academic structure called X-teams** (where X denotes cross-functional).

Through X-teams, **faculty-led teams will reshape core technical ECE curricula in the middle years through novel and proven 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 for future smart systems,**

including security and privacy. Collectively, we refer to this as the RIDE Professional Formation Pedagogy (PFP). Professional formation in RIDE PFP will also be informed by ISU's S-STEM funded E2020 Scholars Program (see Prior NSF Support and Institutional Information) [3]. The premise for our revolutionary approach is something we teach our engineering students: the power of teamwork to successfully achieve results when confronted with problems that require substantial effort along with diverse skills and perspectives [4]. We are faced with a complex educational ecosystem in the professional formation of engineers. Moreover individual courses are becoming increasingly complex, having online resources, multimedia technologies, and diverse learners. Course design and adoption of innovations are constrained by the time and expertise of individual engineering faculty members, especially in relation to education research. We propose to create X-teams of ECE faculty, engineering education and design faculty, industry practitioners, context experts, instructional specialists and teaching assistants. X-teams will redesign second- and third-year core, technical ECE courses guided by RIDE PFP evidence-based practices. The X-team instructional model shifts the paradigm from the traditional single-instructor course, in which an ECE professor designs and teaches the course, to a multi-designer model with either single or multiple teachers. This model is inspired by the work of Bess and associates [5]; 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 [6]. 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. W.J. McKeachie wrote: "Jim Bess has produced a scholarly, intriguing, revolutionary book that could, if implemented, transform higher education in the twenty-first century." [5]

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 [7], and in recent programs from Harvard [8] and ASEE (I-Corps L) [9]. However, the model has not been fully implemented or studied as a strategy for managing courses and faculty in an academic department. An X-team will bring together requisite content and process expertise to support the RIDE PFP.

A key proposed innovation of RIDE PFP is design thinking [10-29]. Design thinking is the way designers identify needs, frame problems and provide solutions through a series of iterative cycles. We will promote design thinking (DT) both for students in a course as part of their professional formation and for X-team members redesigning a course, leveraging DT education experts on our project team (Yilmaz and Mina). Innovative design requires asking different questions, exploring both the problem and solution space in depth, and thoroughly evaluating the generated ideas. In fact, design entails the simultaneous development of both a solution to the problem and an understanding of the problem itself, called "problem-solution co-evolution" [30, 31]. Thus **X-team members using an iterative design thinking process will enhance their understanding of RIDE PFP strategies at the same time they are integrating them into courses**. This iterative process will include generating a series of potential ways to deliver the topics (divergent thinking) and combining and synthesizing them into practical means to integrate into the curricula (convergent thinking). The process will draw on the diverse backgrounds of X-team members, including industry practitioners. As design thinking requires a creative act supported by reflections at every stage, instructors will change their perspectives in creating new pedagogical materials. As students will be involved in this iterative process, this approach will extend ownership of the course to the students and seed their entrepreneurial thinking processes as they approach their careers.

Course redesign will emphasize the priorities of IUSE/PFE with particular attention on evidence-based pedagogical practices that improve design learning (e.g., through design thinking) and that make the course more inclusive. [10, 32, 33] 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 [10]. 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. In current engineering education curricula, the focus is mainly on convergent approaches, in which deep reasoning questions lead to 'the' answer. We propose to make effective inquiry an integral part of an ECE course by reviewing and adapting suggestions from the literature; for example, Dym et al. have offered ideas, such as writing exam questions in a way that requires students to generate concepts by asking generative questions and then offer solutions based on deep reasoning questions [10].

We also propose to make inclusive teaching an integral part of an ECE course by reviewing and adapting published recommended practices as well as using insights from our own research studies. Scutt et al. have described seven key practices for creating gender-inclusive STEM classrooms. They emphasize social and cultural factors and conditional effects (when the influence of an environment or experience differs for different groups) in the transformation of the education ecosystem [33]. The practices are divided into two clusters, skills and scaffolding. The skills cluster encourages educators to foster calculus, spatial reasoning, communication abilities, and resilience. The scaffolding cluster identifies active expert roles, clear feedback in grading, and restructuring group work. They cite the importance of mastery experiences, which relate to self-efficacy in Social Cognitive Theory [34], including elements such as hands-on experiences, real-life application, and problem-based projects [35]. Their work offers suggestions for putting the research into practice in the classroom. The NSF-funded WEPAN-led Engineering Inclusive Teaching project and webinar series also provide research-based practices that will be studied and applied by X-teams guided by expertise on our project team (Constant) [32]. The inclusive teaching and design thinking practices are synergistic and support professional formation.

The X-teams will not work in isolation. X-teams will serve as change agents for the rest of the department through communities of practice that will be formed during the project, 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. As Simon Sinek so simply stated in *Start with Wh*y [36], "People don't buy what you do; they buy why you do it. And what you do simply proves what you believe." 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." **Y-circles, comprised of X-team members, faculty, staff, and undergraduate and graduate students in the department, will engage in a process of discovery and inquiry to bridge the engineering education research-to-practice gap. Y-circles will contribute to an organizational culture that fosters and sustains innovation** [37, 38]. They will facilitate emergent change strategies identified by Borrego and Henderson to increase use of evidence-based teaching, such as bringing faculty together to scaffold community development; moving decision-making further from the top; investing in employees' personal mastery, shared vision and team learning; and encouraging new ideas and team-level questioning and revision of mental models [39]. Y-circles will be vital to departmental change processes using an agile framework that blends several documented change theories including collaborative transformation (ISU ADVANCE), crucial conversations and essential tension [40-44].

Figure 1 illustrates the RIDE transformation built around X-teams and Y-circles. The circular arrow represents the cycles of development for students and faculty. The "del" shape as the top half of the "X" signifies the technical/professional growth of students through the middle years. The "delta" as the bottom half of the "X" signifies the departmental change processes. Labels identify various features and results.

What will be different? The project will lead to (1) radically different department structures and practices for teaching and learning in core ECE courses (X-teams); (2) advances in scholarly teaching and education research department-wide (Y-circles); (3) ECE student professional formation and inclusion through contextual design thinking and E2020 skills development in the middle years (RIDE PFP); and (4) a more agile, less traditional, department able to respond to industry and society needs, sustain innovations, and serve as a model for ECE, computing and engineering departments across the country.

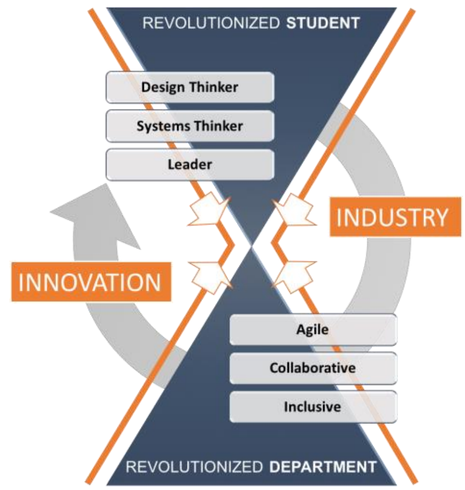

Figure 1. The RIDE transformation.

What is success? In short, success is delivering on the vision – the vision of the RIDE project and the vision of the institution. Iowa State University and the College of Engineering have attained record undergraduate enrollments in part through attracting students to "Choose Your Adventure" and to "Be Greater Than You Imagined" (respective recruiting tag lines). In fact, the latter was created as part of ISU's NSF-funded STEP grant involving project team members [45]. The ECE Department now ranks second nationally among all U.S. ECE departments in total undergraduate enrollment, and second nationally in computer engineering degrees awarded [46]. However, we want to impact the future engineering and computing workforce beyond sheer numbers. The RIDE project represents a trailblazing vision for the department. We will be successful if the ECE middle years include and engage all groups of students in the adventure of ECE, and prepare both students and faculty to be greater than they imagined in the responsible development of ECE technologies.

B. PROJECT PLAN AND EVALUATION FRAMEWORK

It's the way you ride the trail that counts. – Dale Evans

The proposed RIDE project directly and comprehensively addresses the NSF IUSE Professional Formation of Engineers (PFE) initiative and the Revolutionizing Engineering and Computer Science Departments (RED) program goal to make groundbreaking developments at the department level to enhance student success on PFE pathways and to engage faculty in PFE. The RIDE vision articulates the following goals:

1. Collaborative department structures and innovative, inclusive practices for teaching and learning in core ECE courses;
2. Advances in scholarly teaching and education research department-wide;
3. ECE student professional formation and inclusion in the middle years with an emphasis on design thinking and professional engineering identity; and
4. An agile department able to respond to industry and society needs, sustain innovations, and serve as a model for ECE, computing and engineering departments across the country.

Specific objectives to achieve these goals include:

1. Reshape core technical ECE curricula in the middle years through novel and proven 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 for future smart systems, including security and privacy. (RIDE Professional Formation Pedagogy)
2. Develop X-teams, a revolutionary cross-functional, collaborative instructional model for course design and professional formation.
3. Support an iterative design thinking process for X-teams to enhance their understanding and integration of RIDE PFP strategies.

4. Implement a transformation process for the department through Y-circles, applying appropriate theories and techniques to engage faculty, bridge the engineering education research-to-practice gap, and build an organizational culture that fosters and sustains innovation.
5. Investigate research questions to better understand and influence student development, faculty development, and department culture and climate.
6. Promote recognition and incentives for faculty who apply scholarly practices in core courses and engage in the scholarship of learning.
7. Advance engineering education research as a domain in the department, college and university.
8. Collaborate with national networks and major partners for dissemination and adaptation.

Industry involvement in X-teams, RIDE PFP, and the middle-years student experience is highlighted in **letters provided from industry professionals** who serve on the department's External Advisory Board. Institutional support for the department and faculty incentives are described in the **letters from the engineering dean and department chair**.

B.1. Project Activities and Management

The objectives will be accomplished through activities to implement X-teams, RIDE PFP in selected ECE courses, and Y-circles. These project activities will leverage various prior and current departmental and team member activities and institutional resources described elsewhere in the proposal (Institutional Information and letters in Supplementary Documents section, Facilities/Resources section, and Results of Prior NSF Support). Thus a substantial foundation and rich context are in place to help achieve project objectives.

B.1.1. X-Team Activities

X-teams will redesign selected core technical ECE courses in the middle years to implement the RIDE Professional Formation Pedagogy (PFP). Course redesign will give particular attention to evidence-based pedagogical strategies that improve design learning (e.g., through design thinking) and that make the course more inclusive. The aim of X-teams goes beyond training faculty in new teaching methods to changing department structures and culture for engaging faculty in a new way of teaching. This new way of teaching is mandated by future scenarios of engineering education [47]. IEEE education leaders co-authored the scenario planning, and IEEE is interested in the results of this project (see letter). This project will address both faculty and program dimensions of the scenario planning through models and processes that target both individuals and organizations, including faculty motivation [48, 49].

An ECE faculty member is the discipline content expert on an X-team and will be the classroom leader. Cross-functional roles on the team include professional/contextual content experts and various process experts in domains such as pedagogy, assessment, design thinking, inclusive teaching, industry practice and others. As course implementation proceeds, the team uses inquiry-based approaches, gains more experience and collects more evidence, thus deepening and widening its knowledge base. This knowledge becomes an asset for the team and department for future development. Ideas for pedagogical solutions will be explored using an iterative design thinking process. Classroom experiences will be redesigned by interviewing students who took the courses previously and developing new course materials around the data collected by brainstorming and then prototyping. X-teams and other faculty will participate in an annual design thinking workshop to initiate the five steps in the process:

1. <u>Discovery:</u> 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. <u>Interpretation:</u> The group synthesizes the discussion to create a series of questions, such as, "how might we provide opportunities for interest-driven learning?"
3. <u>Ideation:</u> The group generates a diverse range of ideas that will include tools and processes that can be used in the curriculum.

4. <u>Experimentation:</u> The team prototypes several of these ideas and creates a vision for short and long term plans in order to continually build out this approach over time.
5. <u>Evolution:</u> Solutions will be tested, and there will be dedicated times in faculty meetings to reflect on the experimentation and learn from each other.

The outcomes of these yearly workshops will be collected as a set of guidelines to inform faculty as they reformulate their courses and student experiences, including feedback collected from pedagogical prototypes.

B.1.2. Middle-Years Courses, PFP and the Student Experience

Engineering education researchers have presented effective techniques for the second and third years of an engineering curriculum, including practices in ECE [50-52]. Studies have identified the importance and effectiveness of research-based instruction strategies (RBIS) in engineering and in particular for ECE disciplines [39, 53, 54]. In [54], a large survey of ECE faculty shows that most are aware of RBIS, but two primary barriers to adoption are: (1) time taken from lecture, and (2) time needed for preparation. Instructors and X-teams will learn from these efforts to pilot effective strategies for RIDE PFP in two EE and two CPRE required core courses to start with:

- **Introduction to Signals and Systems (EE 224):** signal manipulations, system properties, impulse response, convolution, Fourier series, Fourier transforms, sampling and reconstruction, modulation and demodulation.
- **Analog Circuits (EE 230):** 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.
- **Introduction to Embedded Systems (CPRE 288):** embedded C programming, interrupt handling, memory mapped I/O, elementary embedded design flow/methodology, timers.
- **Operating Systems (CPRE 308):** 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. Course redesign will focus improving design learning (e.g., through design thinking), integrating professional skills (e.g., leadership and other E2020 skills such as systems thinking) and socio-technical context, and making the course more inclusive [3, 7, 10, 32, 33]. Instructors and X-teams will review and adapt suggestions from the literature, like those mentioned in section A, and follow the process outlined above in B.1.1. Intel, Rockwell Collins, and Texas Instruments have already signed on to collaborate on the redesign of these courses (see letters).

In these courses, students learn about many fundamental ECE technologies, and **this learning will be transformed with a socio-technical context to go beyond the hardware, software and interfaces toward responsible development** [1]. What happens when smart systems – self-driving cars, smart homes, delivery drones, medical devices, health monitors (to name only a few) – which will function as part of a nearly autonomous ecosystem, encounter failures, attacks and privacy issues at societal levels? The complexity of these systems necessitates addressing security and privacy risks at design-time often involving fundamental electronics and computing technologies. Students will need to broaden their analysis and design skills to create solutions that work for individuals and society. A project team member (Mina) is an award-winning educator having extensive experience using inquiry and critical thinking in his engineering classes [52, 55-59]. In addition, team members are experts in cybersecurity education at all levels (led by Jacobson).

X-teams will be responsible for assessing student learning outcomes related to technical and professional skills and new mindsets in these pilot courses. Our department has two well-established and accepted assessment tools that are already used by faculty: ABET evaluation rubrics and OPAL. OPAL is an online framework used by the College of Engineering for assessing professional skills during internships [60]. In addition, a team member (Burt) has expertise in assessing engineering students' learning and development

[61]. His work and research will enhance our progress. In particular, he will help train X-teams to more effectively use research-based assessment metrics [62, 63].

In addition to integrating professional formation into core courses, we will review and strengthen other curricular and co-curricular activities in the middle-years experience (see academic, social and professional support opportunities for students in Institutional Information/Supplementary Documents section and Facilities/Resources section). We will partner with campus programs that support specific groups of students such as the Program for Women in Science Engineering (via project team member Chrystal) and the Engineering Admissions Partnership Program for community college transfer students (via project team members who helped create the program through an NSF STEP grant). These programs offer various types of professional development including leadership development, and we will work with them to add new dimensions to their programming and seek their advice to make department activities more inclusive.

B.1.3. Y-Circle and Departmental Change Activities

Y-circles in RIDE will effect change in the department through three strategic change processes: Collaborative Transformation, Crucial Conversations, and Essential Tension. Collaborative Transformation (CT) is a product of ISU ADVANCE, an NSF ADVANCE program, designed to create the infrastructure for transforming university structures, cultures, and practices. CT 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 [40]. CT has been sustained and adapted through the Office of the Provost as the Department Enhancement Program (DEP). The ISU DEP is a systematic method for gathering and analyzing information about the culture of a department's work environment. This information is then used to draft a brief report for the faculty that can be used to further department goals. DEP gathers in-depth, confidential qualitative data from departments as well as information about department organization and governance. Focus group and interview data provide a better understanding about issues facing a particular department. The DEP program is described in more detail in the Facilities/Resources section. We will refer to it as CT-RIDE.

Department chairs at Iowa State, including team members (Jiles, Shelley), have participated in Crucial Conversations (CC) training conducted by a certified trainer at ISU as part of a professional development series [42]. The premise of this approach to enhancing organizational effectiveness and maximizing positive outcomes through interpersonal interactions is that the most fundamental element of organizational learning and growth is honest, unencumbered dialogue between individuals. 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. We plan to use the CC approach to facilitate meetings among faculty, to foster a safe environment during the change process, and to better understand faculty attitudes. We will refer to its use as CC-RIDE.

CT-RIDE, CC-RIDE, and Y-circle activities will result in questioning old assumptions and creating newly shared meanings. In the spirit of Kuhn's theory [43], we are seeking 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. Kuhn was cited in relation to educational transformation [44] where new ideas are perceived as undermining traditional practices. This results in Kuhn's so-called essential tension between the old and the new, between tradition and innovation [41]. Essential tension will be used to facilitate dialogue within the department. It is important that the tension generated through open expressions of differing views be contained through skillful moderation, to build toward as much agreement as possible starting from elements of shared agreement (Crucial Conversations). Doubts, unanswered questions, and feelings of dissatisfaction among members of the department are expected through this process and will need to be understood and moderated.

B.1.4. Project Management

Cross-functional teaming characterizes the RIDE project in management as well as other activities. An agile management process uses high-performing, cross-functional teams to continuously improve results through reflection and feedback. The Scrum agile process is used to develop software products, however, its use is expanding to other areas that benefit from cross-functional interactions, attention to good design and a working product, stakeholder collaboration, and response to change. Since that fits RIDE's needs, we will be organizing project activities and responsibilities using an agile mindset and Scrum-like structures. Scrum has also been described as culture change agent. The following table outlines our approach in Scrum terms [64].

Product	Product Owner	Scrum Master/Coach	Team Members	Stakeholders	Sprint Period	Number Sprints/Yr
PFP Course, Student Dev	Course Instructor	RIDE Professor	X-Team	Various (students, employers, etc.)	2-4 weeks	Approx. 12/AY
Faculty Dev, Dept Structs	Dept Chair	RIDE Professor	DEP/CT/CC facilitators, X-team leaders	Y-Circle, advisory boards, institution, NSF etc.	8-10 weeks	3-4/AY
Project Outputs, Outcomes	RIDE Director	RIDE Professor	Project team, Working groups	Department, boards, partners, NSF, etc.	6-8 weeks	Approx. 6/yr

A "sprint" is a cycle of development in Scrum in which the team conducts planning (prioritizing the stories and features to focus on), stand-ups (plus/delta discussion of progress), demonstrations, and retrospective. In essence, a sprint represents some measurable change, and bigger change will take several sprint cycles. Producing a final product involves a series of sprints. We will adapt Scrum roles and sprint cycles for our project purposes. "RIDE Professor" refers to an ECE professor on the project team who will serve as Scrum Master, and this will vary during the project. The "RIDE Director" will be one of the co-PIs. Not shown in the table are outside experts that are consulted as needed. The experts within the project team are actively involved as Scrum Team Members in sprints, including our experts in engineering education research and social science. Throughout this proposal, we have cited team members' expertise and backgrounds. We have taken a **team approach to meeting (and exceeding) RED expectations for engineering education research and social science expertise** as follows (listed alphabetically):

- **Engineering education research**: Brian Burt (co-coordinator), Doug Jacobson, Mani Mina, Sarah Rajala, Diane Rover, and Seda Yilmaz (co-coordinator)
- **Social science**: Lisa Larson (co-coordinator), Sarah Rodriguez (co-coordinator), and Mack Shelley (internal evaluator)

Biographical sketches, funded research, and publications of these experts reflect multidisciplinary, scholarly, and award-winning excellence. ECE disciplinary expertise is provided Jacobson, David Jiles, Phillip Jones, Mina, Rover, and Joe Zambreno. Inclusion expertise is contributed by Lora Leigh Chrystal and Kristen Constant. Notably, many of our project team members have previously and currently work together on highly successful NSF and other educational projects. The PI team will be responsible for overall project management, communication and evaluation, including annual site visits by NSF and reporting. RIDE project team members will disseminate findings in their professional communities.

B.2. Research Plan

Research studies will be undertaken to:

1. Understand (extract and characterize) how educators involved in X-teams use design thinking to reshape the curricula with new pedagogical solutions.
2. Understand how the RIDE PFP in the middle years affects the professional formation of ECE students, in particular development of a professional ECE identity as design thinkers.
3. Understand how ECE students move within the middle years and access resources to overcome barriers, make choices, and persist along their educational and career paths.

4. Understand the effects of department structures, policies, and procedures on faculty attitudes, motivation and actions.

The studies described below will inform and improve RIDE project activities, advance knowledge, and support adaptation by others. Our research design affords us the opportunity to investigate both faculty and student change.

B.2.1. Instructional Heuristics (Lead researcher: Seda Yilmaz)

A project team member (Yilmaz) has created Design Heuristics [18]. Design Heuristics are mental shortcuts that help a designer make use of past transformations of concepts that led to novel ideas. [19] Through the combination of think-aloud protocol studies [12, 27] and the content analyses of expert's design sketches [20] and of award-winning products [16], a set of 77 Design Heuristics were extracted and translated into instructional concept generation cards. Heuristics were tested with a diverse range of participants, both in classroom studies [23, 28, 29] and professional settings [15]. Heuristic is a term used in many domains [65-69]. The approaches from different domains share the goal of the identification of cognitive strategies based on past experience that lead to quick, but not necessarily "correct," solutions.

We will use heuristics theory as the foundation to explore *Instructional Heuristics* practiced by X-teams. Our goal is to document how educators involved in the X-teams use design thinking to explore techniques to change existing curricula to create new pedagogical solutions. Through analysis of interviews and observations of educators' practices, and newly created teaching materials, we will extract and characterize the heuristics that are successful in creating new teaching approaches and assessing student performance from a new lens. The findings of this research will provide the basis for new pedagogy and will be a key means of sharing and disseminating our experience throughout the project. The instructional heuristics will be available to other educators to use and adapt in their own departments to transform their curricula.

B.2.2. Student Development and Persistence (Lead researchers: Sarah Rodriguez and Brian Burt)

Over the past decade, an extensive amount of scholarship and media attention has been devoted to understanding the unique educational experiences and challenges of engineering students, with the concept of identity formation in engineering quickly emerging as an important area of educational research. Within this body of work, studies have examined the formation and reconstruction of professional engineering identities [70-76] to career pathways in industry, research, and academia [77, 78]. From this work, scholars have found that engineering identity development influences engineering interest and persistence [74, 79-82].

Therefore, exploring the professional identity formation of ECE students within the RIDE student experience is crucial to understanding how their identity will develop over time and whether or not that student will continue to grow as an engineering-engaged individual. Research studies will explore both micro- and macro-level influences to understand how ECE students persist. Focused on the professional formation of ECE students as design thinkers, this research will examine micro-level influences related to how students move within the middle years and access resources as well as macro-level influences related to departmental interventions that influence success. Specifically, we will consider the following research questions:

1. How do students within the ECE department describe initial and continuing engagement with the ECE discipline? In what ways, if any, do emerging identities shape (and reshape) individual perceptions towards ECE?
2. What instructional interventions focused on design thinking are most influential in the development of a professional ECE identity?

The research study will be guided by Social Cognitive Career Theory (SCCT) [83], which is a theory that describes the process by which students choose majors and careers. A number of important studies demonstrate the utility of SCCT in predicting intentions to pursue and persist in STEM majors. SCCT is a theory of career development with roots in social constructivism and posits that the career choice process occurs as a result of adolescents and young adults learning through interactions with others and through activities that have career-related value. This learning is a function of the individuals' environments, their individual characteristics and personal inputs (race/ethnicity, gender, social class), and socialization processes. Through repeated activity, modeling, support from significant others, and feedback from important others, young adults develop specific skills, set performance standards, and develop confidence (self-efficacy) for specific activities and tasks, while simultaneously forming expectations about future outcomes of their performance (outcome expectations). Through these mechanisms, individuals develop particular vocational and educational interests over time, which lead to choices and goal actions of further activities, and eventually to career (vocational) decisions and persistence in these careers [83].

The research team will focus on in-depth examinations of the design thinking engineering identity development process of ECE students, capturing key elements related to self-efficacy, outcome expectations, and goals that may contribute to either the challenges to and/or the success of students in ECE developing and sustaining an engineering identity. The primary methods for data collection will be pre-interview questionnaires, semi-structured interviews, and document review. Working with departmental administrators, we will use purposeful sampling [84] to identify a cohort of students participating in these activities for individual interviews. A semi-structured interview protocol [85] will be developed to elicit information from student participants about background, initial interest in ECE, academic and social experiences in educational settings, influence of design thinking on personal and professional development, and future goals in engineering. Interviews will be transcribed and coded through a systematic, inductive approach [86] to capture emergent themes across student interviews at the institution.

Focus groups with X-team members and administrators will take a social psychological approach [87] to guide focus group discussions. Topics for discussion will include development and perspectives of design thinking instruction, and future plans for sustainability and scalability of design thinking efforts at the institution. Similar to student interviews, data analysis will be focused on coding discussion content and developing consistent themes across conversations. We will also collect observational data on design thinking activities at the institution. Data gathering will include field notes during observations and researcher journaling after each observation [88]. Observed activities will include formal academic experiences (e.g. classroom, laboratory), informal academic experiences (e.g. meetings with faculty/staff), and formal social experiences (e.g. student organization meetings). We will also collect documents related to the RIDE PFP, including materials detailing initial development of design thinking in at the institution. Each data source will provide insights from multiple perspectives on the professional formation of ECE students as design thinkers. Data triangulation will provide holistic, in-depth accounts of how the design thinking experience in the department affects the professional identity formation of ECE students.

B.2.3. Faculty Motivation (Lead researchers: Lisa Larson and Mack Shelley)

For X-teams and Y-circles to succeed, ECE faculty must be motivated to change their well-defined means of constructing and teaching their discipline-specific information. We will examine faculty motivation using a psychological theory called Self Determination Theory [89]. Deci and Ryan used SDT to explain how the social environment can assist people to internalize behaviors that are not initially valued or intrinsically appealing to them. When behaviors are internalized, people own those behaviors as their own, persist at those behaviors, and perform those behaviors at a high level. SDT identifies three fundamental needs that must be met for faculty to engage successfully in a transformation of teaching. Those needs are: relatedness (a sense of belonging to a faculty community that interacts with them regularly and cares about their welfare), perceived competence (faculty feel like they can develop their teaching competence), and perceived volitional autonomy (faculty feel they have freedom to choose how they transform their courses). For example, for relatedness, faculty should see modeling of desired behaviors by other faculty that they are connected to and who care about them. We envision this support through X-teams and Y-circles.

The research questions to be addressed through study of Y-circle processes (CT-RIDE and CC-RIDE) are:

1. What department structures, policies, and procedures will be identified through Collaborative Transformation (the Department Enhancement Program) that act as barriers to RIDE goals?
2. Does participating in Y-circle and X-team processes result in more faculty satisfaction and engagement based on SDT needs?

Using action-oriented research, CT-RIDE (DEP) will result in an action plan created by a subgroup of the faculty for consideration by the full faculty within the department. Identifiable products (materials, practices, policies, and structures) that are developed or affected in response to the action plan provide significant markers for institutional change. Research related to SDT needs considers change at the individual level. Thus this study will examine change strategies found in two of the four categories given by Borrego and Henderson, based on whether individuals or environments/structures are changed, such as faculty learning communities, learning organizations, and complexity leadership [39].

Several value propositions defined in recent research on engineering faculty motivation are congruent with SDT [90]. New research on faculty motivation based on expectancy value theory studied three categories of competence beliefs: content knowledge, process knowledge, and interdisciplinary work [91]. This research, also congruent with aspects of SDT, reinforces the X-team model proposed in this project. These studies and other research [49] on faculty motivation will inform the development of RIDE project components. SDT is also the basis for a related project called Intrinsic Motivation Course Conversion by the iFoundry at the University of Illinois [48]. Their course design method focuses on students' intrinsic motivation to learn.

B.3. Barriers and Sustainability

Potential barriers to achieving project objectives include (but are not limited to): the threat of change overwhelming other influences and making faculty reluctant to participate; inconsistent or insufficient communication and interaction that lead to ineffective or unproductive processes; different norms, structures and expectations that are difficult to reconcile; and various barriers to adopting research-based instructional strategies in ECE [54]. We expect that the motivation theory and research will help us address faculty issues. Careful monitoring of the processes will bring attention to issues that can be resolved and process improvements. Skilled facilitation of the processes and awareness of discipline-specific issues may avoid certain barriers [92-95].

Another challenge for the project is that a new department chair will be in place near the start of the project. This situation is elaborated on in the letters from the current department chair (Jiles) and the engineering dean (Rajala). We have taken steps to mitigate the risk, including having our engineering dean, who is also an ECE faculty member, serve as co-PI on the project. Also, through agile management, we emphasize shared leadership. Nonetheless, the department chair is vitally important, and fortunately ISU has extensive support for chair training, including the DEP program. As noted in the dean's letter, we view the new department chair as an important dynamic to be studied in the change process, and our situation gives us the unique opportunity to do so.

In the interests of sustainability, we have proposed project structures and processes through which organizational qualities that support and sustain innovations can be implemented and monitored. [37, 38] These qualities coincide with faculty motivation (SDT-like); encouragement, collaboration and group support in the work environment (agile-like); and resources and recognition (as in institutional letters).

B.4. External Advisory Board

The RIDE External Advisory Board will provide expert input and advice regarding project objectives, offer focused assessments, and share their external perspectives. The board members will be stakeholders in the agile change processes. The board will be chaired by Dr. R. Alan Cheville, Bucknell University (see letter).

Dr. Cheville brings expertise as an engineering education researcher and administrator and experience with departmental leadership. Other members of the board will be selected in consultation with Dr. Cheville. One or more members will represent the department's existing external (industry) advisory board (see letters from representatives). The board will be diverse, having expertise and backgrounds across areas of the project and representing various stakeholders and underrepresented groups. The board will meet formally once a year to review the project. They will have access to project reports during the year and have opportunities to discuss them and provide feedback. We anticipate that the annual meeting with board members will have active sessions that engage members in the change process.

B.5. Evaluation Plan

Mari Kemis, Interim Director of ISU's Research Institute for Studies in Education (RISE), will serve as the lead external evaluator for this project with support from staff in RISE. RISE's role will include: (1) initial refinement of the evaluation plan and any revisions throughout the project period, (2) monitoring project progress towards completion, and (3) evaluating project outcomes by collaborating with project leadership on data collection processes and procedures, development of instruments and protocols, and determination of the utility of the evaluation results. The evaluation plan is driven by the goals and objectives of this project.

Evaluation tasks, outcomes, and methods are described in Table 1. The evaluation will utilize a mixed-method design, including qualitative methods, such as in-person interviews, focus groups, observation, and reflection, and quantitative methods based on surveys and institutional records. Both formative and summative evaluation will be conducted and the results of those evaluation efforts will be reported. The formative evaluation will assess initial and ongoing project activities such as faculty engagement, stakeholder participation, student experiences, and change. The formative evaluation will examine the extent to which the proposed activities are implemented and program goals are achieved. The summative evaluation will assess the quality and impact of the implemented project. Sustainability, replication, and lessons learned will be assessed. The process evaluation will assist the project as it is implemented, providing routine reporting of information that documents progress toward goals and suggestions for improvement. Given the five-year duration of the project, it is anticipated that evaluation data will provide increasingly accurate metrics of project progress and success over time. Metrics may be adjusted as needed, to adapt to possible changes in participants, circumstances, and the project context.

Evaluators will participate in routine meetings with the project leadership team and share results at least semi-annually. A comprehensive evaluation report will be submitted to the project leadership team annually. The project team will be responsible for the daily implementation of the research plan, including data collection, analyses, and reporting related to the research questions. External evaluation activities may benefit the project's research goals (i.e., the evaluators may collect evaluation data that would also support research questions), and will collaborate with the researchers as needed.

B.6. Mentoring Plans

X-teams and Y-circles involve faculty, staff and students and provide structured avenues for mentoring. Mechanisms will be in place for frequent interaction and feedback, team learning, peer support, and scaffolding of individual and community development. Y-circle participants who gain knowledge and an understanding of the emerging paradigm become mentors for others within and outside the circles. Incentives for faculty to participate are listed in the letters from the department chair and engineering dean, in addition to funding from the grant. Project leadership will also build in value propositions that motivate and satisfy faculty [90, 91]. Other participants in Y-circles will be mentored, or coached, through the processes, with inquiry, feedback and reflection reinforcing their participation. Graduate (and undergraduate) students serving as teaching assistants will be involved in the Y-circles. The project will also reach out to NRT and IGERT graduate education/research training programs in the department (see Facilities/Resources). Undergraduate students will be actively involved in X-team focus groups and other RIDE activities and will be mentored through frequent interactions and feedback. Postdoctoral associates will be mentored as described in the Postdoctoral Mentoring Plan.

B.7. Roadmap for Scaling and Adaptation

Project results will be disseminated through large national networks. Project team members have been active with IEEE University Programs, which is interested in this project for their Early Career Faculty Development webinar series (see letter). ISU is a member of the NSF-funded Center for the Integration of Research, Teaching, and Learning (CIRTL) Network (see Facilities/Resources section). We will widely disseminate project strategies and research findings via network webcasts. Additional dissemination will be leveraged through the National Alliance for Broader Impacts led by the University of Missouri, in which ISU plays a central role (see Facilities/Resources section). Further leveraging will be explored through NCWIT (project team members represent ISU as a member), WEPAN (project team members are leaders), and NSF's network of ADVANCE programs. These networks and partners offer the potential to impact many institutions beyond ISU. Active participation and leadership by project team members in numerous engineering education professional organizations and research communities will provide additional opportunities to extend the work to others.

C. BROADER IMPACTS

It gives women a feeling of freedom and self-reliance. I stand and rejoice every time I see a woman ride by on a wheel. – Susan B. Anthony

The broader impacts (BI) of this project intersect various BI areas, ranging from enhanced infrastructures to workforce development through PFE. Broader impacts are also derived from mentoring (B.6) and scaling and adaptation (B.7). The paramount broader impact focus of this project is broadening the participation of underrepresented groups in ECE, especially women. ISU's undergraduate female enrollment in ECE averages 3% below the national average in electrical engineering and 4% below in computer engineering. The department's efforts to address this under-representation of women are informed in part through an external assessment of diversity and inclusion conducted in 2014 by Partners for Educational Development [96, 97]. The PfED report found that department retention patterns align with the literature on individual and institutional factors affecting the first and second year experiences as critical points in the academic pathway [98-104]. The qualitative climate study was formulated around factors drawn from evidence-based research including pre-college programs, financial resources, learning environment and interactions, undergraduate research training, mentors and role models, systemic support structures and interventions, and career/professional development. Findings suggested that institutional factors are significant in impacting retention of female undergraduate students in ECE and affect students' individual perceptions and behaviors. From themes that emerged from the study, both strengths and barriers were identified. We used specific findings as the basis for an NSF S-STEM proposal that is pending, and partnered with the ISU Program for Women in Science and Engineering to leverage their programs. The RIDE project's proposed activities that focus on inclusion will help us achieve increases in the percentage of undergraduate women enrolled in ECE majors from 8% (current) to 12% (national average), and longer term to 16% (college average).

Other specific activities contributing to broader impacts include: collaboration between the College of Engineering and the School of Education to draft a plan for an interdisciplinary graduate program in engineering education (see letters); support from the college to institute a new college-wide faculty award recognizing excellence in the scholarship of learning and its application; leveraging administrative support and the change strategies to enhance the visibility of engineering education research; extending PFE to the pre-college level through the department's statewide outreach program called IT-Olympics (team member Jacobson), which has strong industry partnering and administers the NCWIT Aspirations Award for the state of Iowa (see Facilities/Resources section); involving professors of practice; and mentoring of postdoctoral associates, faculty, and students involved with the project.

Table 1. Evaluation Plan

Evaluation Tasks	Outcomes	Methods
Conduct process evaluation.	Improve team communication and collaboration. Evaluate functionality and utility of materials and methods. Assess progress in meeting goals. Integrate and build upon past results to improve the project.	Participate in routine meetings with project leadership team. Develop and conduct annual survey or interview with leadership and other stakeholders.
Finalize working evaluation plan to guide project management and link activities and results to outcomes.	Ensure project indicators and outcomes are being appropriately evaluated. Ensure the IRB approvals are obtained. Ensure that instruments and other protocols are used appropriately.	Review evaluation plan annually to make sure that any changes in activities or project focus are addressed. Complete IRB applications and modifications as needed. Complete reporting as required.
Establish baselines for student retention, attrition, and graduation.	Attract and retain diverse students in ECE. New practices result in greater degree of inclusion, equity, and diversity.	Obtain annual data to establish trends and monitor impact, through university record data and survey of stakeholders.
Evaluate X-teams.	Develop and test new pedagogical models and practices for teaching to develop students technically and professionally as engineers.	Conduct surveys and interviews with participating and other faculty. Review program materials.
Evaluate faculty attitudes and skills.	Change practices and attitudes about professional formation and learning. Support and understand how faculty develop and use design thinking skills and create inclusive, design thinking-driven, and professional formation-rich learning experiences. Increase faculty motivation and incentives. Provide recognition and rewards for engaging in scholarly practices.	Conduct surveys, focus groups, and interviews with participating and other faculty. Conduct baseline data collection and analysis in year 1 to gauge faculty attitudes and follow up annually. Conduct periodic surveys of workshop activities as a formative evaluation task. Review scholarly activities annually, including research generated directly from the project.
Evaluate student attitudes and skills.	Change practices and attitudes about professional formation and learning. Support and understand how students develop design thinking skills and professional identity. Enhance the climate for students in the middle years.	Conduct surveys, focus groups, and interviews with participating students. Conduct baseline data collection and analysis in year 1 to gauge student attitudes and then follow up annually.
Evaluate engaging stakeholders.	Involve industry partners in the change process.	Review project records and materials. Conduct survey with stakeholders.
Evaluate departmental change.	Develop departmental structures, policies, and procedures for teaching, educational scholarship, and rewards. Implement change strategies involving established theories/practices and cycles of collaboration/interaction, communication, reflection, and results. Study effect of new department leadership during change. Evidence of shared language, improvement goals, and values within the department.	Review project records and materials. Conduct surveys, focus groups, and interviews with participating program faculty, other faculty, and college administration.

D. RESULTS FROM PRIOR NSF SUPPORT

Social science expert Larson was a leader on NSF grant HRD-06003999, "**ADVANCE Institutional Transformation: Comprehensive Institutional Intervention Strategy at Iowa State University**," 8/1/2006-7/31/2012, $3,296,000. **Intellectual Merit:** ISU ADVANCE [40] utilized a multi-level collaborative effort to produce institutional transformation that aimed to result in the full participation of women faculty in STEM fields in the university. **Broader Impacts:** One broader impact of ISU ADVANCE is expansion from the original 3 colleges focused on STEM to all 7 colleges at the university.

Co-PI Rover is the faculty director for NSF grant HRD-0963584, "**I3: Strengthening the Professoriate at Iowa State University (SP@ISU): A Campus Network to Enable Strong Science and Diverse Communities**," 7/1/2010-6/30/2016, $1,248,727. **Intellectual Merit:** SP@ISU (www.spisu.iastate.edu) supports faculty as they develop BI activities for NSF proposals, integrate these activities into their research program, and document their BI work for the promotion and tenure process. **Broader Impacts:** Resources are provided/disseminated locally and nationally, contributing to stronger participation of both STEM and non-STEM faculty, postdoctoral scholars, and graduate students.

Co-PIs Rover and Shelley were PIs for NSF grant 0807051, "**E2020 Scholars: Advancing the NAE Vision**," 7/15/2008-6/30/2014, $600,000. **Intellectual Merit:** The E2020 Scholars Program provided scholarships for cohorts of undergraduate engineering students and student development and learning in professional skills: leadership, global awareness and understanding, systems thinking, and innovation and entrepreneurship. **Broader Impacts:** The E2020 Program created a student-centered, inclusive learning environment attractive to diverse students. (www.engineering.iastate.edu/e2020)

Education research expert Yilmaz is PI for NSF grant TUES Type II-1323251, "**Evidence-based Pedagogy in Engineering Education: Design Heuristics for Concept Generation**," 9/15/2013-9/14/2016, $403,924. **Intellectual Merit:** This project created a body of lessons based on empirically-validated Design Heuristics that can be incorporated directly into existing undergraduate engineering courses. The project is designed to refine this pedagogy through co-creation with engineering instructors from diverse institutions and backgrounds. **Broader Impacts:** The proposal specifically addresses the challenges of transferability and dissemination of pedagogy to achieve widespread adoption of proven practice.

She is also PI for NSF REE-1265018, "**Investigating Impacts on the Ideation Flexibility of Engineers**," 5/1/2013-4/30/2016, $235,437. **Intellectual Merit:** This project supported ABET's requirements for engineering students to attain design abilities, as well as NSF's strategic goal of innovating for society through addressing explicit guidelines and curricular materials that helped engineering students enhance their ideation flexibility. **Broader Impacts:** The Ideation Flexibility Trio (www.ideationflexibility.org) is co-created with engineering educators across the country.

Co-PI Zambreno is PI for NSF CCF-1149539, "**CAREER: Architectural Support for CPU / GPU Hybridization**," 4/1/2012 - 3/31/2017, $466,312. **Intellectual Merit:** This project investigates techniques that minimize limitations of the traditional coprocessing model for Graphics Processing Units, including performance bottlenecks, vulnerable shared memory spaces, and inflexible resource management. **Broader Impacts:** As part of this work, he is creating video game scripting engines [105] in order to introduce programming concepts to high school students. This work was recently featured in the NSF's Perspectives on Broader Impacts publication [106].

Education research expert Mina was PI for NSF DUE-0837314: "**Creating Effective Future Faculty of Engineering**," 9/2009 - 9/2013, $150,000. **Intellectual Merit:** This project developed an approach to mentor/train effective future engineering faculty in engineering to be better educators and become aware of engineering education as a research area. **Broader Impacts:** Training in engineering education research provides professional development and is an investment that potentially impacts many students in engineering and STEM fields. (Co-PIs Rover and Shelley were co-PIs.)

A. INSTITUTIONAL INFORMATION

Demographics and Statistics. Undergraduate and graduate student enrollments and demographics are given in Tables A.1 and A.2. Faculty counts are given in Table A.3. Iowa State University ranks 12th in the nation in engineering bachelor's degrees awarded (1,121 degrees, 2014) and 8th in undergraduate enrollment (7,688, 2014) [46]. The department ranks 2nd nationally in computer engineering degrees (116, 2014), 21st in electrical engineering degrees (105, 2014), and 2nd among all U.S. ECE departments in total undergraduate enrollment. Tables A.4 and A.5 present retention and graduation rates for various groups of ISU undergraduates. The data is made available through the ISU Office of Institutional Research.

Faculty Development and Department Governance. The Office of the Provost offers professional development opportunities for faculty, ranging from mentoring for tenure-track professors to the Emerging Leaders Academy [107]. The department provides faculty mentors for all assistant professors. Development workshops and resources are also available through the Center for Excellence in Learning and Teaching [108]. The department's governance document [109] supplements the ISU Faculty Handbook on policies governing the rights, responsibilities, and performance of faculty.

Department Instructional Activities and Professional Formation of Students. On average 40% departmental effort goes toward teaching, which corresponds to three 3-credit courses per person per year. Workload for a given faculty member is negotiated with the department chair. The student-to-faculty ratio in the department is 24:1. At Iowa State, over 85% of first year students are in learning communities. Students in ECE can participate in various Learning Communities. In 2nd and 3rd-year courses, students attend small faculty-lead group meetings and learn about workplace competencies, contemporary issues, and professionalism and ethics. In their 4th year, students develop electronic portfolios and reflect on their learning. All senior take a year-long capstone design experience, mentored by a faculty member.

In the department, a faculty director of Student Professional Development is responsible for coordinating departmental co-curricular and extracurricular activities that prepare students for the profession. One example is Friday Activities at Noon (FAN) club, which invites students to come view research and other ECE-related presentations and demos. Other examples are Critical Tinkers, a team of students who use critical thinking to create exciting projects, and Digital Women, which supports women in computing disciplines through networking and activities (e.g. dept. supported travel to Grace Hopper).

Prior Efforts at Department Level Reform. Under an NSF-funded DLR planning grant, the department (led by team members Mina, Rover, and Shelley) piloted a curricula model to improve student learning through vertical integration of educational activities [110]. We offered an experimental course sequence during Fall 2004 and Spring 2005, defined as a learning stream. Assessment indicated a stream is an effective alternative to traditional term-based courses. The E2020 Scholars Program [3] (led by team members Jacobson, Rover, and Shelley) is listed under Prior NSF Support. The program included a sophomore seminar with focus on professional formation in the areas of leadership, systems thinking, global awareness, and entrepreneurship. PI Jiles has also conducted curriculum reform [111, 112].

During Spring 2013, co-PI Zambreno convened a task force to examine renovating the curriculum to reflect modern pedagogical practices. It focused on subject connectivity, greater hands-on design experiences, and additional flexibility in years 3-4. An implementation plan was presented to the full faculty in December 2013, where it was thoroughly deliberated and a positive vote was held. Ultimately the reform effort stalled due to faculty concerns, revealing deeper departmental transformation is needed.

Since 2013, the department chair (PI Jiles) and several faculty (including co-PI Rover) have consulted with Partners for Educational Development [97] to promote positive learning environments for students in the department, with a focus on climate for diversity and inclusion. In Nov. 2014, the consultants interviewed undergraduate women students in ECE and delivered a report in 2015 [96]. The study examined personal experiences, academic experiences, confidence, resources used/needed, and relationships with faculty and peers. The study's results form part of the evidence base for this proposal.

Table A.1. Undergraduate Student Enrollment at Iowa State University (2015)

	Total	Fresh.	Soph.	Jr.	Sr.	Women	URM
University	30,034	6,890	6,398	7,020	8,550	12,963	3,826
College of Engineering	7,949	2,201	1,674	1,601	2,433	1,252	967
ECE Department	1,789	488	394	392	515	159	213

Table A.2. Graduate Student Enrollment at Iowa State University (2015)

	Total	MS/MA	PhD	Women	URM
University	5,096	2,438	2,279	2,140	468
College of Engineering	1,363	683	672	321	107
ECE Department	380	178	201	81	29

Table A.3. Faculty Demographics at Iowa State University (2015)

	Total	Full Rank	Associate Rank	Assistant Rank	Lecturers	Other	Women	URM
University	1,973	591	459	414	475	34	718	98
College of Eng.	265	69	81	65	48	2	42	7
ECE Dept.	59	20	25	3	4	7	5	1

Table A.4. Retention and Graduation Rates, Freshmen and Transfers, at Iowa State University

ENTRY TYPE AND YEAR	NUMBER ENTERED	AVERAGE ACT COMPOSITE	RETENTION RATE[1] 1-YEAR	2-YEAR	3-YEAR	4-YEAR	CUMULATIVE GRADUATION RATE 2-YEAR	3-YEAR	4-YEAR	5-YEAR	6-YEAR	10-YEAR
Freshmen												
2009	4,321	25.0	86.0%	78.2%	76.1%	74.1%		1.6%	40.7%	67.7%	71.3%	
2010	4,532	25.0	87.7%	80.3%	75.8%	75.9%		2.2%	43.2%	68.8%		
2011	5,023	25.0	85.8%	79.4%	76.9%	74.1%		1.8%	43.6%			
2012	5,352	25.0	87.1%	80.6%	76.5%			2.2%				
2013	6,064	25.0	86.4%	79.4%								
2014	6,010	25.1	87.1%									
ISU Average	4,615	24.8	85.5%	78.0%	74.9%	73.1%		1.6%	38.7%	65.5%	69.4%	71.3%
Transfers												
2009	1,550		80.2%	72.7%	69.1%	67.7%	14.3%	44.4%	59.6%	64.3%	65.8%	
2010	1,589		80.4%	74.5%	70.8%	69.2%	14.9%	46.1%	62.4%	66.8%		
2011	1,692		82.2%	75.7%	72.1%	70.7%	15.6%	47.9%	64.8%			
2012	1,744		80.7%	73.8%	69.6%		15.1%					
2013	1,945		82.7%	75.2%			14.9%					
2014	1,892		81.3%									
ISU Average	1,560		80.0%	73.2%	69.9%	67.6%	15.1%	45.4%	61.5%	66.2%	67.5%	67.4%

Table A.5. Retention and Graduation Rates by Groups at Iowa State University (2015)

GROUP	1-YEAR RETENTION RATE — ENTERING CLASS 2012	2013	2014	4-YEAR GRADUATION RATE — ENTERING CLASS 2009	2010	2011	6-YEAR GRADUATION RATE — ENTERING CLASS 2007	2008	2009
Race/Ethnicity									
African American	75.9%	74.8%	78.2%	22.2%	20.3%	25.4%	45.3%	50.0%	48.1%
American Indian/Alaskan Native	85.7%	84.6%	64.3%	37.5%	25.0%	22.2%	41.7%	50.0%	37.5%
Asian	89.2%	86.4%	88.4%	32.8%	41.5%	46.4%	68.6%	65.7%	61.7%
Hawaiian/Pacific Islander	100.0%	83.3%	75.0%	NA	16.7%	66.7%	NA	NA	33.3%
Hispanic	85.5%	79.4%	82.1%	30.8%	31.6%	31.1%	60.6%	54.2%	63.6%
Two or More Races	86.9%	77.0%	83.2%	36.4%	34.2%	39.3%	80.0%	50.0%	57.6%
Total Minority	84.8%	79.7%	82.7%	29.0%	30.9%	34.3%	53.0%	56.3%	57.9%
White	87.3%	87.5%	88.0%	42.3%	44.9%	45.4%	69.2%	70.8%	73.4%
Gender									
Female	87.8%	87.0%	88.3%	51.4%	54.4%	53.5%	72.4%	72.1%	75.1%
Male	86.6%	85.9%	86.1%	31.6%	33.8%	35.6%	64.4%	66.3%	68.2%
Total	**87.1%**	**86.4%**	**87.1%**	**40.7%**	**43.2%**	**43.6%**	**68.0%**	**68.9%**	**71.3%**

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