Work in Progress: Reinventing the Undergraduate Electrical Engineering Curriculum to Address Tomorrow's Cross-Disciplinary Global Challenges

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WIP: Reinventing the Undergraduate EE Curriculum to Address Tomorrow's Cross-Disciplinary Global Challenges

Introduction

The rapid technological advancements over the past century that enabled the computer and information age have fueled the passion of electrical engineering (EE). Today, technologies created by EE's have become so pervasive that they are often taken for granted as engineers develop new technologies with global impact. While advancements continue in specific EE areas, high-impact solutions to grand challenges in areas such as healthcare, education, and transportation are increasingly cross-disciplinary in nature, requiring collaboration across EE areas and other disciplines.

EE has traditionally comprised of fixed sub-disciplines working in isolation, and lacking in diversity of knowledge and background. But, the EE discipline is at a turning point, where success of EE's can no longer rely exclusively on advances with the technical discipline (e.g., the integrated circuit, personal computer, smartphone), but also the ability to interface technological advances across highly complex systems and across broad application areas. There is a clear need to reinvent curricula in EE, and in particular to prepare tomorrow's engineers to be competitive in a global world and to emphasize and support student diversity. Here we describe our current ongoing efforts to address these needs through a revised EE curriculum. This effort includes the development of a vision for transforming the EE curriculum, and current proposed activities to formalize integrative laboratory and design activities and engaged learning in the EE undergraduate program. The vision presented in this work will certainly have similarities to curriculum development at other institutions, where we believe that primary distinguishing factors are the establishment of relevance at an early stage of the curriculum, and development of abilities to solve cross-disciplinary challenges with high complexity.

Background and Motivations

The current EE curriculum at most institutions is traditional in providing a rigorous education grounded in the fundamentals of the discipline and then providing depth in sub-disciplines of the field. However, EE enrollments are declining [1], both nationally and at the University of Michigan (UM), and the undergraduate student population is predominantly male and white or Asian. According to national statistics [2, 3] , only 12.6% of students earning a BSEE are women and 22.6% are historically under-represented minorities (URMs). At UM, those figures are 19.5% and 13.0%, respectively. In general, diversity in the workforce is anticipated to improve performance [4-6], and employers of EE graduates have expressed the desire for a more diverse pool of job candidates. The lack of diversity and increasingly inter/multi-disciplinary nature of engineering have been primary motivations to re-examine the structure of the undergraduate EE curriculum. The current program is a traditional curriculum that only minimally seeks to train students with team skills, societal relevance, and cross-disciplinary content to prepare students for today's workforce; and does not directly promote diversity.

At UM, we have completed exploratory studies through focus groups with undergraduate engineering students and analysis of student transcripts, as well as a review of curriculum

innovations implemented at other institutions. These suggest the importance of both (1) providing students with an early integrative foundation to allow them to make informed decisions in choosing an engineering discipline and to effectively navigate through their degree program and (2) offering more complex, hands-on experiences that are aligned with solving high-impact problems. Introducing these changes in the curriculum is expected to both provide students with the tools needed to address tomorrow's cross-disciplinary global challenges, and to directly promote a diverse student population. This approach for curriculum reform fits within an overall vision developed for transforming the EE discipline, as illustrated in Figure 1. The vision seeks to develop EE's by combining skills to address challenges of high technical complexity and societal relevance, while developing a spirit of community and collaboration in the profession.
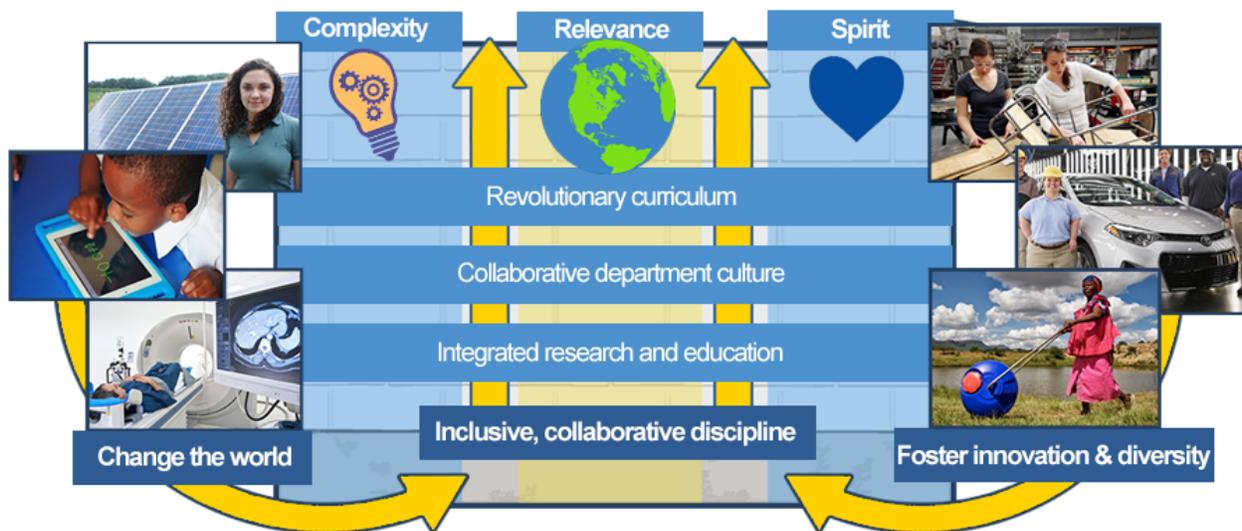

Figure 1: Illustration of a vision to transform the EE discipline to address tomorrow's cross-disciplinary global challenges.

Objectives of Curriculum Revision

A combined review of our curriculum and development of the overall vision to transform EE resulted in three overarching desired student outcomes:

1) Ability to apply a deep understanding of EE fundamentals to future technologies
2) Ability to solve open-ended problems with great complexity
3) Ability to work with a team with diverse backgrounds and perspectives.

The current curriculum is recognized as successful in training students in the fundamentals of EE, and has traditionally been the major emphasis of curricular discussions among faculty. Outcomes 2) and 3) are aligned with the identified shortcomings in training students with sufficient team skills, societal relevance, and cross-disciplinary content to prepare students for today's workforce, and in directly promoting diversity. To achieve these student outcomes, the following have been identified as goals for curriculum change:

1) Teach fundamentals that reflect current and future challenges of the EE discipline
2) Provide an early and integrative exposure to EE
3) Incorporate an experiential learning activity in the junior year

The first objective in teaching fundamentals is a continued process of adapting our current practice of providing a rigorous foundation in EE. The second objective seeks to provide an early integrative foundation by interweaving the diversity of technical areas in EE at an early stage. This requires the development of dedicated project-based integrative lab and design coursework at the sophomore and junior level. The third objective aims to prepare students to tackle high-impact problems by introducing a formal requirement for an immersive learning experience that addresses a high-impact engineering, scientific, or societal challenge of the student's choosing, allowing students to acquire rich, hands-on experience with complex, real-world societal problems. These second and third goals to reinvent the EE curriculum – an early integrative foundation and an immersive learning experience – are expected to foster a sense of community, sustain passion in the discipline, and deepen students' abilities and motivations to participate in impactful activities that will change the world. As a result, the new curriculum will attract and retain a more diverse student body and prepare student with the broad EE skillset required to address cross-disciplinary global challenges.

Figure 2 illustrates three example student trajectories through the envisioned new curriculum. Each student's curriculum begins with the same foundational EE coursework, but the experiential learning activity and subsequent course elections vary according to their interests. Student 1 researches neural biosensors, then she enrolls in the sensors and microsystems technical track; Student 2 co-ops at Intel, assisting in the development of a specialized microprocessor, then he enrolls in courses in the computing and embedded systems technical track; and Student 3 collects data from local schools to improve education in Ghana while studying abroad there, then he elects to take courses in data analytics. The three collaborate on a senior capstone project that requires their collective expertise to develop a wearable physiological monitor for children with autism, and each student follows a distinct post-graduation path. Student 1 pursues a faculty career in academia, Student 2 takes a job in industry, and Student 3 becomes a social entrepreneur. Although each student engages with a unique experiential learning activity, each sees the cross-disciplinary nature of EE at an early point in their curriculum, and the three collaborate on a diverse senior design team to solve a problem with societal relevance.
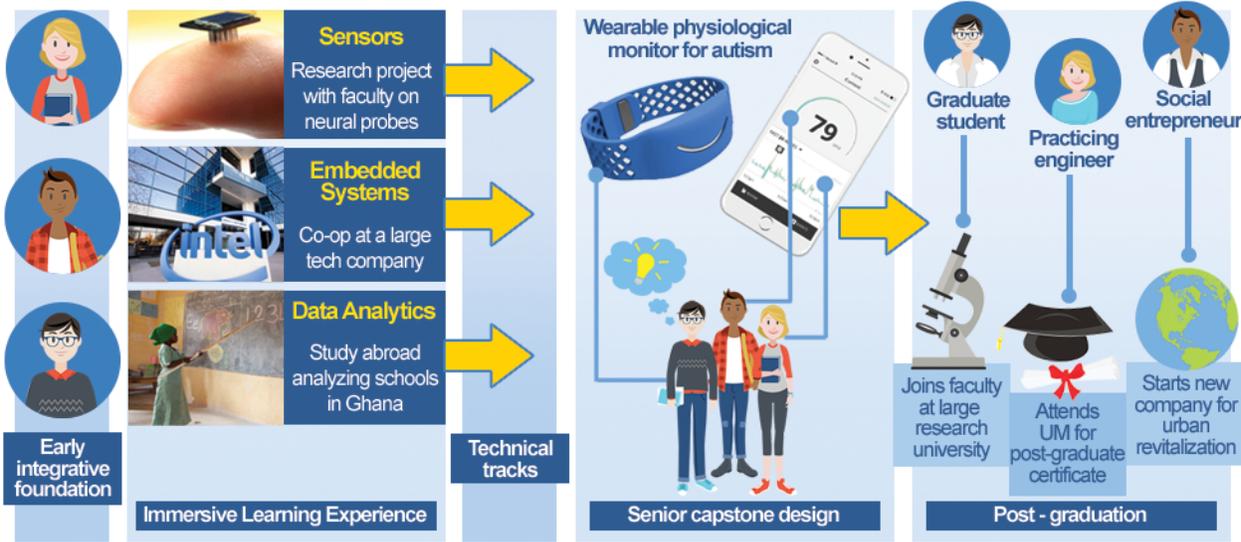

Figure 2: Three sample student trajectories through an envisioned revised EE curriculum.

Integrative Lab and Design

We are currently developing integrative laboratory and design courses to be taken in conjunction with existing foundation courses. These new laboratory and design courses will make explicit connections between technical areas, encourage system-level thinking, and require students to apply their developing technical skills to contemporary engineering challenges. These courses will include laboratory experiments, design projects, and applications that combine conceptual knowledge across multiple foundation courses. The integrative lab and design would introduce and/or deepen student understanding of EE concepts using hands-on laboratory activities. All of the laboratory activities will integrate multiple subfields in EE, and will be in a team-based collaborative environment and containing a creative/design component rather than a scripted sequence of tasks. One example activity might be the design of a crash avoidance system for autonomous vehicle, addressing foundational topics such as electronic devices and electromagnetics and involve sensing devices, radio-frequency and optical techniques for proximity detection, computing, and system-level design.

The integrative lab and design coursework would help to provide a systems-level perspective across broad subject areas in EE, and how these areas combine to address complex problems. These courses would extend the teaching of design at the sophomore and junior year, and allow students to directly apply EE fundamentals that they are learning to relevant real-world problems. The challenges faced by students in these courses will help them develop skills necessary for life-long learning, and to solve cross-disciplinary global challenges. The hands-on and team-based nature of the integrative laboratory and design courses, and their focus on impactful applications, will provide a foundation for our students to apply technical concepts to real-world problem, to build a sense of community among the student population, and to sustain their passion about electrical engineering as they continue their studies.

Immersive Learning Experience

With the exception of students who voluntarily engage in extra-curricular student groups and project teams, undergraduate students at UM work primarily on an individual basis, inhibiting collaboration and a sense of community among the student population. As a result, it is difficult for students to see connections between technical topics, and students with diverse interests and perspectives can be discouraged. Focus groups of EE undergraduate students at UM offer some insight into student perspectives: approximately 20% of participants requested that more project-based activities be incorporated in the program. To excite students about EE as an academic discipline with great potential for innovation and societal impact, we are seeking mechanisms to formalize engaged learning activities as a part of a new curriculum. In such engaged learning activities, students apply their knowledge in the discipline to address a high impact engineering, scientific, or societal challenge of the student's choosing. The introduction of an immersive learning experience (ILE) requirement could be satisfied by a variety of options with differing ways of broadly applying knowledge of the discipline to address larger issues in a team environment. The ILE is envisioned as a degree requirement, while the actual credit hours may vary widely depending on the option chosen. There are three classifications for the ILE that are currently under consideration:

1) Undergraduate research projects as a part of a research team
2) Project with industry as a part of a co-op program or industry-sponsored team project
3) Project team with campus group (project may be conducted off campus)

These experiences will leverage faculty research activities, partnerships with alumni and industry, and numerous active campus groups. Critical to the professional formation of tomorrow's engineers, the ILE activities are expected to deepen students' abilities and motivations to participate in impactful engineering projects, while connecting them to research, professional, and societal communities aligned with their interests. Currently, a large fraction of our students are already participating in such activities, while a goal is to ensure full participation and quality of activities to pursue. Senior exit surveys for EE grads at UM in spring 2017 (64 respondents out of 108 graduates) indicated that 56% of student respondents participated in undergraduate research, 72% in internships/co-ops, 45% in student project teams, and 90% participated in one of the three options. While the level of participation indicated by the survey respondents is highly encouraging, the extent of these activities in achieving the objectives of the ILE is unclear. Options to satisfy the ILE requirement would be subject to review by an academic committee to ensure adequate depth, team environment, and broader impact of the project.

The ILE requirement would include the expansion of undergraduate research opportunities to improve engineering practice. Engaging undergraduate students in research is known to be a high-impact educational practice that can positively influence academic achievement and retention (e.g. [7, 8]), especially for women and URMs [9, 10]. Opportunities for undergraduate students to participate in research at UM include a formal program that engages about 1,200 first- and second-year students in faculty research for work-study financial aid or academic credit; a 10-12 week paid summer program; and research activities with faculty on a volunteer basis, through directed study projects for credit, and external research programs. While undergraduate research participation has been very fruitful, projects are limited in number and duration. More importantly, these projects are usually highly individualized rather than collaborative. From the faculty perspective, participation of undergraduate researchers can positively influence and contribute to research groups and can provide a means for faculty to connect their research activities to undergraduate education. However, barriers to including undergraduate students in research include the short timeframe for student participation (and long ramp-up time before effectively contributing) and logistics associated with recruiting and managing students. To address these concerns and expand undergraduate research for students, we propose to expand offerings of multi-disciplinary research project teams and to promote faculty involvement and leadership in undergraduate research activities by establishing a faculty incentives model.

Engagement with industry offers a means for students to directly apply their skills to real-world problems. Co-op and internship programs will provide one opportunity for an ILE, provided that the student participation would build on technical skills of the degree program and be a part of a multidisciplinary team environment. Industry sponsored projects can also provide an ILE, through existing programs on multi-disciplinary design offered for all engineering. Similar to the above research projects, faculty involvement in establishing industry sponsored student projects within the department would be incentivized.

Student project teams , which range from national and international competitions to interdisciplinary projects with partner organizations around the globe, can provide a highly valuable ILE. At UM, students often view their participation in such project teams as one of the defining moments of their undergraduate experience. Examples of competition teams include the Solar Car, MHybrid Racing, Spark (electric motorcycles), and MAAV (autonomous aerial vehicles), which have all demonstrated success on the national and/or international stage. Non-competition project teams include BLUElab (developing socially, economically, and environmentally sustainable technologies) and M-HEAL (projects aimed at healthcare in underdeveloped communities).

Implementation and Current Status

The curriculum revision described presents an overall grand vision to transform the EE program at UM. While successful implementation may be transformative for EE, there are numerous barriers that need to be overcome including resistance to change among faculty and availability of resources (or willingness to re-allocate resources). The vision described in this work has developed over several years of discussion involving committee meetings, faculty meetings and retreats, and input from students and employers. While the student outcomes pursued in this work are broadly agreed upon as aspirations for our program, time that students spend in the degree program is precious and highly constrained; approximately 62 out of the 128 credit hours required for the program are taken in the department, while the rest are math, science, intellectual breadth, and general electives. As a result, it has been difficult to reach consensus on how to best structure our program to achieve the curriculum reforms described. Clear tradeoffs have been identified in the ability to introduce curriculum changes (integrative lab and design course sequence and immersive learning experience) with more traditional coverage of EE topical areas (while reconfiguration of technical tracks are not expected to have substantial tradeoffs). In particular, considerations have been debated among faculty of breadth versus depth in technical content, flexibility versus uniform coverage of EE topical materials, and practicality of implementing curricular change versus achieving curriculum objectives. Champions of the curricular reform have needed to clearly articulate how proposed changes are meaningful and appropriate for preparing future engineers, and that subtracting existing curriculum requirements are truly justified. At present, the integrative lab and design course sequence has been approved by faculty and is under development. Activities to offer engaged learning experience are under expansion, with discussions continuing to determine how to formalize the ILE in the degree program. As curriculum development proceeds, transformation of upper level elective courses (along technical tracks) and the senior capstone design will be pursued consistent with the vision of preparing EE graduates to address tomorrow's cross-disciplinary global challenges.

REFERENCES

[1] S. M. Lord, R. A. Layton and M. W. Ohland, "Trajectories of Electrical Engineering and Computer Engineering Students by Race and Gender", *IEEE Transactions on Education* **54**, 610-618 (2011).

[2] *Profiles of Engineering and Engineering Technology Colleges*, Washington, DC, American Society of Engineering Education, 2015

[3] *Science and Engineering Indicators 2014*, Arlington, VA, National Science Foundation, 2014

[4] J. C. Blickenstaff, "Women and science careers: leaky pipeline or gender filter?", *Gender and Education* **17**, 369-386 (2005).

[5] C. Corbett and C. Hill, *Solving the Equation: The Variables for Women's Success in Engineering and Computer Science*, Washington, DC, American Association of University Women, 2015

[6] S. Lewis, R. Harris and B. Cox, *Engineering a better workplace : a diversity guide for the engineering profession*, Barton, A.C.T, Institution of Engineers Australia, 2007

[7] C. Craney, T. McKay, A. Mazzeo, J. Morris, C. Prigodich and R. de Groot, "Cross-Discipline Perceptions of the Undergraduate Research Experience", *The Journal of Higher Education* **82**, 92-113 (2011).

[8] S. H. Russell, M. P. Hancock and J. McCullough, "Benefits of Undergraduate Research Experiences", *Science* **316**, 548 (2007).

[9] R. S. Hathaway, B. Nagda and S. R. Gregerman, *The relationship of undergraduate research participation to graduate and professional education pursuit: An empirical study*, 2002

[10] T. L. Strayhorn, "Undergraduate research participation and STEM graduate degree aspirations among students of color", *New Directions for Institutional Research* **2010**, 85-93 (2010).