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The Art of Product Engineering: Integrating IoT Systems and Human-centered Design Principles for Entrepreneurs of Tomorrow

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Abstract

In the ECE department at our university, we have been surveying and studying the needs of our stakeholders for many years: our students, managers from companies that hire our graduates, our faculty and staff. In the 2016-2017 academic year, we undertook an initiative to build a new type of capstone course to meet the needs of our stakeholders, and the result was our course. The course is an ambitious, two-quarter sequence that integrates full-stack software development on an IoT hardware platform, business basics, human-centric product design, entrepreneurship, leadership, and a rigorous hands-on lab component. It places customer needs at the heart of product design, allowing the students to get an authentic product development experience. Our aim through it all is to provide our students with practical, hands-on experience in building a novel IoT/software product for a new market of their own choosing, while working in the setting of a startup competition.

During the early planning stages for this course, it became clear that, while our students had excellent math and theory skills, they needed training in software development, systems thinking, and other hands-on skills. We wanted our ECE students to graduate with the ability to confidently walk into their future employers' office and know how to do the things they so passionately studied. Our experiment has proven to be a tremendous success as student after student has returned to us and declared that the course was the very reason they received their internship or job.

In this paper, we will discuss the structure of the course sequence, highlighting how we combine the four pillars of software, hardware, product design (including user experience, information architecture, and human factors), and entrepreneurship into a seamless classroom experience. The course covers many topics at a rapid pace, preserving the value of theoretical knowledge while emphasizing experiential learning. We will highlight the lessons that we have learned along the way, what has worked out very well, what we are still trying to figure out, and what plans we have for the future offerings of this course.

Introduction

Prior to 2015, the curriculum in our ECE department would have best been described as being "traditional" in the sense that students graduating from the discipline had a very strong foundation in the basic theoretical tenets of ECE, making them strong candidates for graduate school. Yet, with all of that theoretical and mathematical rigor of traditional education, the students lacked cross-domain learning experiences or understanding of the path that awaited them if they pursued a career in industry.

After listening to much feedback from our alumni and industry partners, and having discussions with colleagues at other top-tier universities, it became apparent that there was a growing need for hands-on engineering experience with emphasis on industry standards and professional expectations. Not only did our ECE students lack the experience of building solutions end-to-end, but they were also at a heavy disadvantage in the job market because of their limited software skills, and a minimal understanding of the workforce they would soon join.

With a strong push for experiential learning across the entire school of engineering at our university came the impetus to develop a capstone course sequence in ECE that would give students an authentic "practice run" at being professional engineers. Principles such as agile development, entrepreneurialism, systems thinking, and software/hardware design and integration became cornerstones of the course. We wanted these terms to be more than just platitudes, so we crafted learning outcomes that would evaluate the students' conceptual understanding of these principles as they progressed through the two-course sequence.

Furthermore, when it came to good foundational software development experience, ECE students simply had very few options. Therefore, in addition to crafting a startup-like experience for the class cohort, we wanted to weave a full-stack thread throughout the curriculum. We had no intention of making ECE students change career paths to become software developers, but we wanted them to understand the ecosystem – knowing how databases interact with servers in building IoT products, for example.

The Agile Experiment (History of the Course)

To meet these challenges, we established three project objectives. Our first objective was to find more agile and sustainable processes to develop and continuously improve engineering curriculum. The second objective was to improve our pedagogical methods to make the classroom learning experience more engaging [1]. The third objective was to develop a new learning experience for our students that produced measurably better learning outcomes.

An essential idiom that emerged from student, faculty, industry, and professional surveys was the widespread use of agile methodologies. Since these methods are part of the curriculum we teach students to inform planning and execution skills, we decided to use these same agile techniques to develop our curriculum. Through continuous multi-week phases, to incrementally improve sections of our curriculum. At the end of each iteration, we collect feedback from students, learning experts, other stakeholders, and our own experiences. We use this feedback to choose the next set of objectives to improve curriculum. In this way, our students enjoy a curriculum that is better aligned with trends and practices in industry.

To achieve our second objective of continuously improved pedagogy, we have once again relied upon agile methodologies. Before each term, we survey literature related to teaching and learning, and select methods that look promising and are achievable in our timeframes. Our first approach was to build reusable learning modules. Next, we utilized an "inverted classroom," where students watch lectures before lecture and participate in-class discussions. Both these techniques produced results that were in line with expected research results.

In the last year, we have begun relying on "real-time" learning interactions, such as "live chat," "live polls," and automatic lecture transcripts that are automatically integrated with the learning materials. Student surveys show a 90% approval rate for all three of these methods. Students appreciate the immediacy of these methods on their learning. As instructors, we appreciate that we get immediate feedback from students that allows us to alter our teaching plans on demand to better align with the student experience.

Our latest pedagogical approach is to use what we call the "Agile Iri-Kumi." We create a learning experience where students interact with each other in real-time related to the course work. One set of students is the "learner" and the other the "teacher" (in roles that change). Students work through a learning challenge in a shared context where the rest of the class benefits from their interactions. Students have rated exercises based on this method as "very good" in surveys.

Our final objective, better learning outcomes, is measured in terms of: 1) a student satisfaction survey; 2) industry feedback; 3) CAPE reviews of the courses, and 4) post-graduation feedback from students. Student surveys and course reviews rank the results of this program in the top 1-2% of engineering courses. We are most pleased, however, with student successes post-graduation. Alumni of the course have taken on roles in startups, industry, and government organizations. They work as engineers, product managers and owners, and intra/entrepreneurial roles at companies including Google, Qualcomm, and Apple. We frequently receive messages from them with phases like, "These were the best courses I took at the university, and led to my getting my current position."

Validated Learning

Over the course of the last five years, we have made a concerted effort to remain attentive to the feedback from students matriculating out of this capstone sequence. Since we spend the better part of an academic year working closely with them on their projects, we develop a strong rapport with the students, even after they graduate.

A number of our former students have gone on to explore their own startups as a result of having taken the course sequence or have joined an entrepreneurial team. A few of them who went on to work in industry or pursue product management roles still have active communication with us. In fact, one of our former students actually employed several interns directly from our class because she was so impressed with the experience that she had when she took the classes.

While not having conducted any formal studies yet, we have annual Course And Professor Evaluations (CAPE) in which students provide anonymous feedback in addition to informal surveys that we conduct after each term. We encourage students to be as honest and critical in their evaluations and, time and time again, we have heard students value this course sequence as some of the best material in their undergraduate careers. We also have taken any critical feedback very seriously and addressed the concerns raised by adjusting and improving the curriculum.

We also work closely with the Corporate Affiliates Program (CAP) office, where we listen very carefully to our department's corporate partners. They resoundingly echo the sentiments that we share about a convergent engineering experience and fully support the work that we are doing in our course. In fact, we have received direct project support from several companies as they have seen the value of this capstone sequence.

Admittedly, our measure of success is at best anecdotal for the time being. While we have truly attempted to craft a high-caliber learning experience for our students, the next step is to actually see if the student experience has material impact on them after they graduate, during the hiring process, and then into their careers. We are confident that this is the case, but we need to collect more data in order to substantiate these claims beyond the dozens of kudos we have received over the past few years.

The Course Structure

We have structured the two courses very carefully in order to cover the four pillars of software, hardware, product design, and entrepreneurship into a seamless classroom experience.

In the first of the two courses, students are introduced to a heavy amount of technical skills in the classroom. At a very brisk pace, we teach them the basics of building a technical full stack IoT product, including fundamentals in HTML, CSS, JavaScript, databases, and Python. Additionally, we also prepare them for the second course by introducing them to what we call the "agile business," where students learn about the basics of business operations and product design in the context of a startup environment. For the final project, students work in teams to identify and propose a possible problem that they will work on in the next course. They prepare an elevator pitch-type of presentation highlighting their key findings prior to ever actually building anything.

The course also has a technical lab component where they work in teams to all build the same functioning system. We frequently change the focus of this project, but in the past they have built smart WiFi plugs, autonomous RC cars, and even indoor drones that detect objects and follow them.

In the second course in the sequence, the focus shifts to students proposing and designing their own product in a mock startup competition. They need to identify a viable problem, prove that a product/market fit exists, conduct customer interviews to discover the needs of their personas, and then build a prototype of the system. In this course, we teach them iterative agile methodologies that are commensurate with current industry practices. During the “Agile Iri-Kumi” each week, the student teams take turns presenting their sprint updates, while a randomly selected team provides them with constructive feedback to improve their design as they iterate to their solution.

The course culminates with a final “investor pitch” presentation. The teams summarize their product discovery findings before a panel of judges and must demonstrate a working prototype of their solution.

What We Have Learned

We feel that it is essential to mention that the work we have been doing to reinvent the learning experience in our ECE capstone course was not undertaken as part of a research effort. Nonetheless, we have benefited considerably from the experience and thought we would share some of our informal findings.

It is readily apparent to a casual observer that engineering students want to be challenged. What is not always clear is how to align learning outcomes with student interests so that they are inspired to push themselves to achieve things that exceed their own expectations. We survey students annually regarding their preferred roles upon graduation and find the responses to be illuminating. About 40% of our engineering students aspire to non-traditional engineering roles – including product managers, designers, broad leadership roles, and frequently intra/entrepreneurial roles. Based on our experience teaching these engineering students in a hands-on capstone course, we have discovered that understanding the professional role individual students want to achieve after graduation, and aligning that role with their personal capstone objectives results in transformative outcomes.

Another surprising thing we have learned from our students is that the most valued technical learning outcome is related to "full stack" systems engineering, including AI and machine learning. The majority of our students are enrolled in the Electrical and Computer Engineering program. Most of our student surveys show that the capstone course is the first experience they have had involving "full stack" systems training. Most report that this "significantly" changes their perspective on their available professional options. Subsequently the university has expanded the number of courses that include hands-on systems engineering – as are many other engineering schools across the country.

Finally, as it happens, the pedagogical improvements took on special significance and importance in the last year as we have shifted to mixed modalities of teaching and learning as a result of the COVID-19 pandemic.

The Future of the Course Sequence

We have lofty ambitions for the class, and we truly believe that we have crafted a novel learning experience that takes a brand-new perspective on educating the next generation of engineers. Yet, we realize that we do not know what we do not know. Currently, our understanding of the success of this course is largely based upon subjective notions of success. We have been extremely busy crafting content that aligns with stakeholder expectations and our perception of industry needs.

In the upcoming months and through the summer, we are hoping to replace our subjective notions of success with tangible metrics. We are aiming to conduct a large-scale survey of alumni who have and have not gone through the course sequence. Our hope is to concretely discover answers to questions such as the following:

1. Did we help in shaping any students into entrepreneurs and/or full-stack engineers who were on a different trajectory before?
2. Did we help in the hiring process?
3. Did we help in the career selection process?
4. Did we help in the career onboarding process?
5. How effective were our pedagogical methods in helping students achieve mastery of technical and non-technical topics?

If this capstone sequence is truly as effective as we believe in preparing engineers for their future employment, we should be able to see a discernible difference. While we did not set out to create this capstone as a pedagogical research project, we are discovering daily that the teaching platform is one that deserves to be studied to fully appreciate and understand the effectiveness of the material on student success.

References

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