Integrating Theory and Practice into a Design Foundations Course

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Introduction

Engineering education scholars have emphasized the need for holistic, integrated engineering education that prepares future engineers for the complex sociotechnical systems (STS) in which they will work [1], [2]. Design courses such as Cornerstone or Capstone courses provide opportunities for students to apply technical learning in a real world context in addition to building professional teamwork and communication skills. However, students often focus more on the technical solutions and deprioritize the contextual and human factors in design. This has been described as an instrumentalist orientation, which focuses on engineering education as a narrow means to solve technological problems and provide job training [3], [4].

Scholars have called for integrating STS theory into engineering education to expand students' understanding of engineering practice [5], [6]. While ethics education is required for ABET accreditation, many engineering ethics units are reductive, based on Western/Global North perspectives, and focused on micro-ethics rather than systematic impact [7]. Nieusma [4] argues that it is important to frame engineering curricula with liberal education that scaffolds students' reflexive practices rather than augment by adding more liberal arts. Similarly, communication should be integrated throughout curricula with multiple opportunities to develop skills through practice [8].

To encourage students to consider the sociotechnical aspects of engineering design, many programs implement a human-centered or user-centered design (UCD) pedagogy. User-centered design courses are strong examples of hands-on, project-based courses that offer students the opportunity to learn to incorporate stakeholder perspectives and iteratively design products for their needs. Students work on a long term project for which they conduct research and information gathering, design ideation, prototyping, testing, and design communication and dissemination [9]. These courses are often offered early in the undergraduate program as Cornerstone courses (e.g., [10]) or at the end as a Capstone course (e.g., [11], [12]). Engineering design education operates through a constructivist model of learning [13], and the principle that students learn best by doing design [14]. Design instruction is typically delivered in a flipped or studio model, through collaborative group or parallel individual work sessions [15]–[17].

User-centered design courses may provide more hands-on experiential learning, but they do not inherently integrate sociotechnical thinking. Previous research has shown that students often separate the social from the technical, and do not fully consider the socio-political

implications of their designs nor their own positionality and power in engineer-stakeholder relationships [7], [18]. Students often have interest in social justice, but the pressures of graded assignments, short academic term timelines, and the job market deprioritize and depoliticize their work [19], [20]. Therefore, theory should be foregrounded and integrated into UCD courses.

Our undergraduate program in Human Centered Design & Engineering recently made major curriculum changes after conversations with current students, alumni, faculty, accreditation stakeholders, and industry partners. As part of this, we have combined some of our introductory courses to create a new cornerstone user-centered design course titled Foundations of Human Centered Design. This new two quarter sequence combines two introductory user-centered design courses, one on the theory and the other on the practice, while also extending the project component from the one-quarter model to two quarters.

In this paper, we present a case study [21] to describe the process we followed for developing the new course design and the major course components, merging previously-separate courses on the theory and the practice of user-centered design. We present auto-ethnographic accounts from our own epistemic experiences based on teaching both the previous and the new version of the courses. We discuss rationale for considering the new structure, integrating multiple academic disciplines, setting up the new course structure, preparing the two-quarter course plan, and the experience of teaching it for the first time. We also address tensions of integrating non-technical disciplines into a design engineering course. In the spirit of user-centered design, we present this as a case study of radically iterating on course design based on stakeholder feedback rather than make small changes to the existing courses.

Context

The authors are part of a Human Centered Design & Engineering department at an R1 university, where the first author is a PhD candidate and the second and third authors are teaching professors. All three earned traditional engineering undergraduate degrees. The first and third authors have been associated with teaching introductory design courses within our department for 5 years, and the second and third authors taught the new foundations course.

Previously, students entering into the major at our department took two separate introductory design courses. The first course was on the practice of design (hereafter referred to as DP), which was a quarter-long project-based course that took students through the entire user-centered design process. Students would begin the quarter by being placed into groups and explore a design problem they are collectively interested in with user interviews and personae building to understand existing pain points, competitive analysis to examine existing approaches, brainstorming potential design solutions, building low-fidelity prototypes, and refining them into high-fidelity versions based on user testing and feedback. The course was taught as a partially flipped classroom, with about half of in-class time dedicated to group work. Outside of class time, students also maintained a sketchbook, where they were required to make at least two

entries per week on potential redesigns to existing systems in their environments that they perceived to contain design flaws.

The second introductory course was on the theory of user-centered design (hereafter referred to as DT), as a quarter-long immersion into technology design practices as a form of world-building and examination of the inner workings of technical artifacts and design methods from multiple social, historical, cultural, and ethical perspectives. The course was conducted primarily as a lecture with in-class discussion and activities, with additional discussion sections containing hands-on design exercises. Students wrote weekly reflections, and the final project was a critique and re-design of the design process.

The perceived need to make a change to the way the department was offering these two courses arose from our experience teaching them and reading end-of-course evaluations, as well as conversations with alumni and industry. A common theme across evaluations of DP over multiple quarters was how students felt starved for time, mentioning how too much was happening in too few weeks, and they were not able to fully master concepts and do good work. Students particularly struggled with a rushed timeline of the prototyping and testing phase of the course that lasted only 3 weeks (out of 10 weeks in the quarter), which resulted in some of them building prototypes that fell short of addressing the root of the problems identified in user research and/or students were not entirely satisfied with. The 10-week timeline also left little time for critique or reflection. Per student evaluations, DT was experienced as too esoteric without a grounded project to scaffold discussion and critique and connect it with their design practice. However, all stakeholders believed that the theory content of DT was important for graduates of our program to be well-rounded critical thinkers and design engineers. Because there is no departmentally-required order in which students take these 300-level classes, the theory and practice courses could be taken in any order and with multiple courses between, which created issues for understanding and shared experiences. Additionally, there were potential college-level changes in technical writing offerings, so we sought to incorporate technical communications into the new curriculum.

Course Design

To design the new 2-quarter foundations sequence, we reflected on our experiences teaching these courses and sought input from a variety of sources. We informally asked graduating students and alumni from our department about their experiences in DP and DT, and what aspects of each they felt were more significant than others. We obtained student feedback through mid-quarter Small-Group Instructional Diagnosis (SGID) administered by independent consultants not involved in teaching the courses. We also consulted former instructors of courses, as well as experienced faculty within the department and our internal undergraduate program committee.

One of the first decisions we made was to establish this course as a 2-quarter long amalgamation of DP and DT, based on a few reasons. We believed that this would address the

common theme of students not having enough time per course component, as we would be able to allocate longer for individual components over 20 weeks instead of 10. Furthermore, we decided to combine the two courses since keeping them separate surfaced a few issues. Students either took them concurrently or in different orders (DP first or DT first). It was always the case that students in any given class were at different levels of familiarity with user-centered design principles and processes. Our intent was that combining the two courses into one would ensure that students within the cohort would be at the same level. Additionally, we sought to build more of a cohort experience where students would have opportunities to build working relationships with peers over the two quarters.

The 2-quarter new foundations course included a select few readings from the set of course readings across DP and DT, primarily motivated by students' mention of displeasure with the volume of readings and most of them being generally esoteric. We compiled readings that had been explicitly mentioned as unhelpful within either previous course evaluations or alumni feedback, and debated the merits of each one. We arrived at a final, curtailed list of readings on STS and design theories organized into units such as design justice [22], [23], the politics of artifacts [24], inclusive design [25], [26], constructing users [27]–[32], prototyping [33] and speculative/discursive design [34]–[37]. These each corresponded with a related individual or group assignment. We also decided to distribute these such that the second quarter can be focused more on the group project and reflection.

The bulk of the work in designing this new course was centered around building the timeline for the group project across 2 quarters. This was one of the primary motivations behind designing the 2-quarter course, in recognition of the fact that students across multiple quarters disliked the amount of time they had to execute the design project, and that doing good design takes time. We structured it such that the first quarter would be dedicated to the planning phase of the project, whereas the second quarter would take them through the prototyping phase. Each quarter featured sketching and theory keyword scavenger hunt assignments.

In the first quarter, students were placed into groups within the second week of class and prompted to explore a design problem around doing "future life together". This purposely vague design prompt allowed for a diverse set of projects. They were challenged to think beyond user interface interactions such as app or website designs as they embarked upon framing a research question and recruiting potential interviewees for user research. Midway through the quarter, they were required to have completed their personae and user journey maps, arriving at a few ideas with design goals and requirements, which they would then sketch out for peer review. At the end of the first quarter, students submitted a finalized design proposal document as a deliverable and presented to an external design review panel of alumni and industry partners.

In the second quarter, students started with a teamwork workshop to assess how they worked together and created a team contract for the remaining weeks of the project. Next, they narrowed down their design ideas and created information architecture, wireframes, and

schematics for their proposed design. This informed a low-fidelity prototype for initial usability testing to get feedback on high level changes. Students used this feedback to iterate into a medium-fidelity prototype. They then used this prototype to design an evaluation plan and conduct multiple rounds of usability testing, arriving at a high-fidelity prototype towards the end of the quarter. They presented these final designs to alumni and industry partners for a design review. During the last class, each team performed a design retrospective. Finally, each team compiled an online portfolio for the entire project and wrote team reflections. A brief outline of the course is shown in Figure 1.

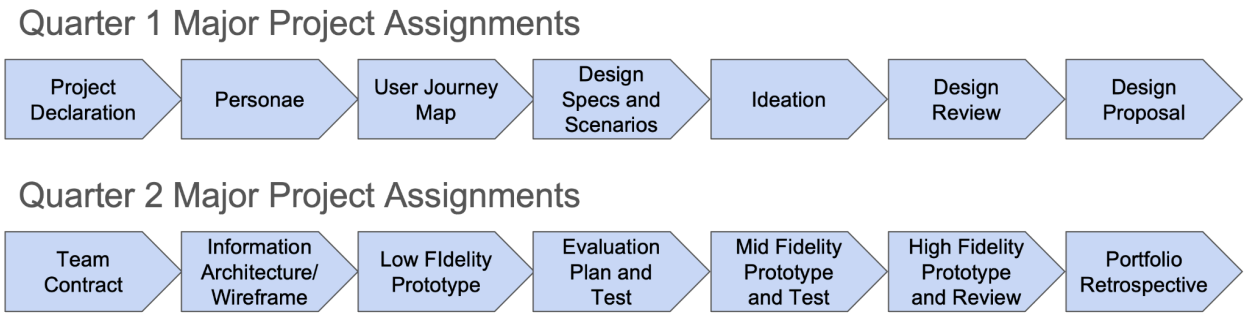

Figure 1: Outline of the 2 Quarter Foundations Course Design Project Deliverables

In addition, students were asked to engage with STS through reading responses, mini design projects, and reflection. For example, after a unit on political artifacts, students analyzed a product related to their project for its politics and developed a short form video describing the product. Towards the end of the project, students used concepts from value sensitive design and discursive design to write a speculative story imagining their product 50 years in the future. For the final assignment, students created a journey map of their experience in the course and critiqued their design process using the theories from the class.

Reflections

From our experiences so far, it is evident that the 2-quarter foundations course is a significant improvement to the previous version of separately offering DT and DP. In particular, students seem to appreciate the extended amount of time that they have to go through the design process, instead of being cramped by the constraint of a single quarter as DP would have imposed upon them. The slower pace afforded more time for comprehensive feedback from the instructors and for students to reflect on their own design processes. It also allowed the instructional team to practice UCD and reflect and adjust the curriculum throughout the 2 quarters by incorporating feedback from stakeholders.

Since the students were allowed to pick their own projects and challenged to think about novel interactions, there were a diverse set of projects and prototypes including a fridge inventory system for multi-person homes, an AR mirror for online thrift shopping, a wearable to

facilitate emotional connection in long distance relationships, improved “third spaces” for students to eat and socialize, bus stop displays for services for people experiencing being unhoused, portable charging stations, and a robot-facilitated icebreaker game. This presented challenges for creating assignments that were relevant for all groups and mentoring appropriate prototyping methods. One instructor had a computer science background and was able to support the digital projects, while the other instructor had a mechanical engineering design background and was able to support the physical projects. This delineation of expertise was not planned in advance but was more helpful than a theory/practice expertise split would have been in the class and is something to explore in future versions of the course.

One of the most prominent signs of the success of the foundations course is the increased quality of student work in the group project. In our role as instructors, we observed that multiple groups used concepts from the STS theory readings in their design processes and exhibited systems level thinking when articulating the rationale for their decisions during Q&A with external reviewers at the design reviews. Although it is not feasible to scientifically compare the quality of different groups’ work across different quarters in DP or those from DT to this course, such an improvement in quality is perhaps to be expected given that students in this course had twice as much time as their peers in DP. Students in the foundations course have been able to make design choices based on extensive reflection, thinking through potential ideas in great depth before committing to executing them. In a similar vein, instructors observed that the quality of student communication also improved in this course as opposed to the writing and oral presentations students would do in a short amount of time in DT, although it is once again infeasible to demonstrate such an improvement definitively.

Multiple students expressed that they benefited from the increased amount of time and detailed feedback from the teaching team and peer and external review of their designs. DP required students to turn in low-fidelity prototypes, conduct one round of user testing and iterate to submit a high-fidelity prototype over a week and a half, which left no room for peer review of the prototypes. Spreading out the prototyping phase over an entire quarter in three stages allowed for the integration of a few rounds of peer review after designing the low-fidelity prototype, such that groups could use insights from it to design a medium-fidelity prototype upon which to conduct user testing. This introduction of peer review within the prototyping process afforded students the opportunity to share skills and ideas with each other, facilitating a collaborative open studio environment. These informal peer reviews also afforded students the opportunity to practice communication skills before the formal design reviews with alumni and industry partners at the end of each quarter provided important real-world critique and feedback.

We encountered tensions fully integrating the STS curriculum into the new foundations course. The salience of the design project often overshadowed the theory readings and assignments [38]–[40]. Some assignments like the theory keyword searches and speculative futures assignment engaged students in thinking about how theory might apply to them as designers, and future iterations of the course will need more assignments that encourage this sort

of application. Some students engaged more with the sociopolitical implications of design than others, which was evident in problem spaces they chose (e.g., support systems for unhoused people) and speculating the potential for unintended harms such as materials used for a physical prototype on a large scale might lead to sustainability concerns.

Another tension we encountered was student critiques of the STS readings as esoteric and irrelevant to their reality as future engineers under capitalism. These discussions became generative as we encouraged students to critique the readings using evidence and counternarratives (e.g., students pushed back the idea that prototyping is a modern phenomenon with examples of historical agricultural prototypes in non-Western countries). In future iterations of the course will continue to try different pedagogic strategies such as group annotation of a paper on tools such as Hypothesis.is and in class activities that apply parts of the reading.

From an organizational and instructional perspective, one of the biggest challenges to note was that despite the rationale behind forming the foundations course was to ensure students would take theory and design components in order, this could not be ensured across the board for all courses in the department. As a result, there was not a uniform experience in terms of what previous courses students had taken (or what courses they were taking concurrently), leading to a vast range of student expectations and skill levels being present within the cohort. In addition, while students were able to build relationships with their teams and cohortmates over the longer timeline, there were still team dynamics issues. In future iterations, there will need to be more teamwork scaffolding earlier in the course.

Therefore, we have promising evidence that our redesign of our departmental introductory design curriculum from the previous version of two distinct one-quarter courses – one on theory and one on practice – into a single 2-quarter foundations course has been an effective and beneficial change. This change occurs within broader curricular changes including introducing courses in Inclusive and Sustainable Design. So far, we have taught this series in class sizes of 40 students. Implementing and scaling a two-quarter course requires building and sustaining a departmental infrastructure for teaching. This includes classroom space that facilitates studio work and group discussions, training for instructors and teaching assistants to mentor projects in active learning style for large classes that meets all learners' needs [41], access to guest speakers from industry, and a program curriculum structure where taking the courses in sequence in a cohort model is feasible and flexible for students. These resources are not always at the discretion of educators and are practical constraints within which we design. We will continue to iterate on the foundations sequence, and we plan to conduct an interview study with instructors and students in future cohorts.

Conclusion

We have presented the process we followed to combine a theory and a practice course into a 2-quarter foundatons course that all students in our program will take. We described the

major components of the pilot course, which has successfully improved students' learning experience in its first offering.

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