Course Design Thinking: Navigating Tensions at the Intersection of Design Thinking and Engineering Course Design

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Introduction

Designing courses and learning activities in engineering is a complex process affected by many dynamic variables: student characteristics, shifting policies, changing technical and professional knowledge, national and global events, and more. While many frameworks and systems exist to support engineering faculty as they (re)design their courses, design thinking has emerged as one viable framework due to its human-centered, creative, diverse, and adaptive nature [1-5]. Still, studies show that certain mindsets and approaches essential to design thinking may be challenging for faculty, especially those in engineering [6]. Thus, if engineering educators hope to leverage design thinking for course design, how might it be accomplished? This study seeks to further understand the intersection between design thinking and engineering course design by investigating two research questions:

1) What tensions are experienced by engineering educators attempting to apply design thinking to the redesign of two courses in the second and third year of an undergraduate electrical and computer engineering program?
2) How do these tensions inform the application of design thinking in an engineering course design context?

The Emergence of Design Thinking in Education

The study of design thinking emerged through efforts to understand the nature of design practice and how, typically successful, designers engaged therein. By understanding these areas, scholars and practitioners could enhance designer education and develop structures and systems to support more effective design among both novice and advanced designers [7]. While the results of this area of study have been widespread and influential, it is widely acknowledged that there is no “one right way” to practice design, no single way designers think. In part, this finding reflects the diversity of design practitioners, who may experience design in a variety of ways [8]. In part, this finding also reflects the diversity of settings in which design is practiced, the changing nature of those settings over time [7], and expansion of design thinking outside of the traditional design settings (e.g., architecture, product design) from which it emerged [4].

One important setting for novel applications of design thinking has been education. Recent years have seen several initiatives intended to bring design thinking into the process of developing courses, curricula, and other learning activities. Some of these efforts provide practical frameworks for engaging educators in the design process. IDEO [2], a leading design consultancy, developed a design thinking toolkit for educators that consists of distinct phases and scaffolded activities in each phase. Tschimmel and colleagues [4,5] developed the E6 framework to bring design thinking to business education, similarly consisting of distinct phases and guidance for each phase. Others have focused on educators themselves. Gallagher and Thordarson [1] describe five roles that education leaders might take to engage design thinking

(opportunity seeker, experience architect, rule breaker, producer, and storyteller), and connect essential practices, habits, and mindsets that will be useful for educators embodying these roles. Moreover, they argue for the importance of building a strong and diverse team and strategically developing mindsets.

While these frameworks provide useful guidance for educators, several elements challenge the sustainability of utilizing design thinking in an education design setting, especially in engineering education. First, as with an adaption of design thinking to a new setting misalignment with extant cultures and practices can be challenge the utilization or adoption of new practices [9]. Limited previous study suggests that such misalignments exist in engineering education settings and have limited the degree to which educators engaged with design thinking-oriented processes in several ways [6]. Second, the changing nature of design problem spaces can necessitate different approaches [7]. Courses and curricula are complex design objects. They affect many diverse users (e.g., students, instructors, staff, etc.). They also contain many dynamic components that can change from semester to semester, or even on shorter notice (as in the switch to online and hybrid learning for many in March 2020). These components may include changing content (e.g., based on evolving technology or employer needs), classroom technology, pedagogical and assessment trends, assessments, pedagogy, access to learning spaces, course formats, and expectations and needs of students.

Our goal here is to understand how design thinking might be applied to engineering education settings in a way that respects the integration and adaptation into extant cultures and practices and is effective for dealing with the complex and dynamic nature of educational design products (e.g., courses).

Design Framework

Many models and frameworks have been proposed to explain design thinking. These range from research-based to practical and generative, and can focus on different abstraction levels (e.g., specific techniques, processes, behavioral enactments). Since our focus here is to explore relevant adaptations of design thinking to a specific setting, we begin with an empirical, comprehensive, and flexible framework identified by Carlgren, Rauth, and Elmquist [10]. We selected this framework for several reasons. First, it is based on how design thinking has been utilized within several distinct, leading organizations, and thus acknowledges potential challenges related to organizational culture or utilization among a variety of stakeholders with differing levels of design thinking expertise. Second, it offers a robust conceptualization across several themes *and* practice dimensions. Third, the researchers' focus was to bridge the theory-practice gap. Finally, this framework resonated with members of the design team with little previous design thinking expertise, thus it offered opportunities for inclusive discussion and development of potential shared visions.

Carlgren and colleagues' [10] framework is organized across two dimensions. The first dimension describes five themes that explain the essence of design thinking (see Table 1). The second dimension describes three levels which these themes can be enacted. The *mindset* level describes orientations among individuals engaging in the process that guide their practice.

The *practices* level describes key activities related to design thinking, that often engaged by teams and can be informed by individuals' mindsets. Finally, the *techniques* level describes more specific activities that scaffold or direct engagement in key aspects of the practices.

Table 1. Design Thinking Themes Identified by Carlgren, Rauth, & Elmquist ([10], pp. 46-48)

Theme	**Description**
User Focus	"[A]n inherent user focus, expressed in terms of empathy building, deep user understanding and user involvement."
Problem Framing	"[R]elat[ing] to the problem at hand: instead of trying to solve the problem, they tried to widen, challenge and reframe it."
Visualization	"[M]aking ideas tangible by means of low resolution representations or mock-ups of ideas or solutions."
Experimentation	"[A] bias towards testing and trying things out in an iterative way, and moving between divergent and convergent ways of thinking."
Diversity	"[C]ollaboration in diverse teams, and the integration of diverse outside perspectives throughout the process."

Our goal in this study is to investigate how each of the five themes projects onto the context of engineering course design at each of the three levels. Carlgren and colleagues [10] provide a large but not necessarily comprehensive list of mindsets, practices, and techniques aligned with each of the five themes, which provides a useful starting point. However, they offer two caveats when the considering mindsets, practices, and techniques unique to each theme. First, within each theme, mindsets, practices, and techniques can inform each other over time. For example, repeatedly engaging in a practice or technique can help one develop a mindset. Second, specific mindsets, practices, and techniques may best align with one theme but connect to multiple themes.

To these caveats, we would also add consideration of the organizational culture. The extant practices and techniques common within a work setting or field, as well as the mindsets of practitioners therein, can influence the degree to which design thinking themes can be successfully enacted. For example, Postma and colleagues [9] describe challenges enacting the *user focus* theme, especially, within even a single project in a large organization. Conversely, the capacity for design thinking within an organizational culture might be bootstrapped through targeted use of design thinking principles. For example, Howard and colleagues [11] discuss the possibility of instilling design thinking via changing mindsets.

Applying the Design Thinking Framework to Course Design

Informed by these caveats, we utilized Carlgren and colleagues' framework [10] to investigate how design thinking could be used in the context of engineering course design. We acknowledge that cultures within engineering education, and more specifically our home department, as well as the habitus we had individually developed throughout our engineering and engineering education careers, might require reframing of the five themes and determine which mindsets, practices, and techniques might be most useful in enacting those themes. In determining these

aspects, we took a reflexive stances, somewhere been the poles of (a) forcing an extant, static view of design thinking into our context and (b) choosing only the concepts and aspects that uniquely fit into our context. Thus, we attempted to adapt the design thinking framework in a way that acknowledged individual habitus and cultural norms while also allowing design thinking to modify them to support more responsive and efficacious course design practice.

Our course design thinking practice has evolved and continues to evolve. While a thorough discussion thereof would be beyond the scope of this work, we offer brief discussions below demonstrating how our team has come to conceptualize Carlgren and colleagues' [10] themes in the context of course design and our primary methods for enacting those themes.

Design Thinking Themes in Course Design

Each of the five themes identified in Carlgren and colleagues' design thinking framework resonated, to at least some degree, with our intrinsic course design processes. For example, the *user focus* theme was evident in our previous course design experiences in that many of us focused on providing rich, engaging, and relevant learning experiences for students and often relied on our understanding of the thoughts and behaviors of previous students. Yet, considering and enacting these themes in our distinct contexts required at least some customization or modification. Sometimes this required adding some context-specific elements to the themes, such as the student- and learning-oriented framings of the *User Focus* and *Problem Framing* themes. Other times, themes evolved in nuanced ways based on our individual and, later, collective interpretations of the themes in the engineering course design context. Thus, we have adapted these themes for greater relevance in the engineering course design context. Table 2, below, lists our current interpretations of each of the themes.

Engaging Each of the Adapted Design Thinking Themes

Applying these themes to a course design process often involved discussion of common practices in more traditional design disciplines, our team members' current practices, and where either (a) current practice could be informed by designerly practices or (b) where designerly practices might need contextual modification. Alongside these discussions, we often discussed the mindsets that informed our current and newly adapted approaches, as well as mindsets we might attempt to engage relevant to our emerging practices. Thus, we found it most useful to describe the practical implementation of each theme in terms of a limited number of practices that (1) sufficiently comprised the theme, (2) resonated with our contexts, proximal capabilities, and course design needs, and (3) could be engaged through paired target mindsets. We list each practice-mindset pair in Table 3, below.

Table 2. Adapted Course Design Thinking Themes

Theme	Adapted Definition
User focus	A user focus ensures that designers meet the needs of users through the design process. This is comprised of two commitments. First is a commitment to uncovering and understanding the experiences, challenges, and needs of users. Second is a commitment to keeping those user aspects in mind and using them to inform work throughout the design process. Here, students are the primary users.
Problem framing	Problem framing represents an open-ended, expansive, reflective, and iterative engagement with the design problem being addressed by the course. Through this process, designers identify problems to address that are based on the core needs of students, allow for focused concept development, and may be dynamically articulated based on new insights and changing course conditions. Problems can focus on a variety of aspects, including (1) supporting desired learning or development outcomes, (2) facilitating new perspectives or mindsets, and (3) improving students' experiences in the course.
Visualization	Visualization focuses on articulating potential solutions to identified design problems. Such visualization can focus on expansion of the base of ideas and concepts the design team works with or expansion of the details of promising concepts. An important feature here is externalizing a designer's internal representations and creating novel, shared representations among the design team. These representations may be multi-modal (e.g., lists of ideas, sketches, connections, physical models). This allows the designers to further identify and explore nuances in the problem and solution space and further articulate and understand designers' visions thereof.
Experimentation	Experimentation focuses on developing prototypes early and often in order to get feedback about the user experience (e.g., from students, student models, proxy stakeholders). Rapid prototyping, evaluation, and iteration allows the designer to identify major issues with designs early, allowing many different solutions to be considered, frequent learning, and continuous improvement.
Diversity	The focus of the diversity theme is leveraging and integrating a variety of perspectives to support aims from each of the previous themes. This involves forming design teams with individuals with diverse expertise, backgrounds, and experiences; ensuring those individuals have opportunities to share differing ideas and perspectives; and creating structures to leverage diverse ideas and perspectives across all other design themes.

Table 3. Practice-Mindset Pairings

Theme	Mindsets and Practices
User Focus	● Empathetic inquiry into the student experience ● Openly bringing diverse student voices into the design process
Problem Framing	● Identifying and translating core needs ● Open-minded reframing and checking of biases
Visualization	● Consciously generating varied, voluminous, and novel ideas ● Actively detailing ideas into testable prototypes ● Expansively and visually concretizing the interconnections within problem and solution spaces
Experimentation	● Frequently developing and testing lo-fi prototypes ● Learning from testing
Diversity	● Collaborating with individuals from diverse backgrounds and perspectives ● Actively ensuring contribution opportunities for all ● Iteratively building a shared understanding of the design context (e.g., course details and operation, user base and experiences, etc.)

Methods

Context

Design thinking was the focus of a larger departmental change effort at a large university in the Midwestern United States. At the center of the project, design thinking was intended as a framework to support course redesign of second- and third-year electrical and computer engineering courses. The goal of this application was twofold: (1) integrate professional formation (e.g., sociotechnical thinking, design thinking, lifelong learning, leadership, etc.) more deeply into and across core technical courses and (2) increase student-centeredness, iteration, and flexible-mindedness among faculty, especially as it related to course design and implementation. Several courses were selected for redesign and course design teams were developed to enact the projects' two goals within each course.

The current case study focuses on two of these course design teams. One team focused on redesigning a course in embedded systems required for all electrical, computer, and software engineering students. The other team focused on redesigning a computer architecture course taken mostly by computer engineering students, often in their junior/third year. These teams consisted of a total of thirteen members from varying departments and academic positions, each recruited to serve a specific function and provide a specific area of expertise. The three of these team members were considered facilitators and design thinking experts. One of the three was a faculty member in industrial design with experience researching and teaching design thinking among a variety of audiences. The other two facilitators were electrical engineering faculty members with experience researching and teaching design thinking primarily among engineering students. Other than three design thinking facilitators, team members had little or no prior formal experience using or studying design thinking. One or more course instructors served as de facto leaders of the teams. After several semesters, the two teams merged into a single team focused

on both courses. The five members of this team, including the two electrical engineering faculty facilitators, are the five authors of this manuscript.

In addition to specific course redesign outcomes, the five members of the combined team had focused on understanding how design thinking can be integrated into the course (re)design process in an electrical and computer engineering department at a large, research-intensive university and developing a model thereof. The overarching methodology of this development was a synthesis of co-creation [12] and the design experiments approach to design model development [13,14]. Co-creation reorients the traditional roles of users, designers, and researchers by more deeply engaging the user throughout the design process and removing the barriers between user research and design [12]. Users collaborate in developing empathic insights, defining needs, and developing solutions with situationally appropriate scaffolding from designers. This approach was favored because it acknowledges the agency necessary to build a situationally appropriate and sustainable change in the way educators in the department develop their courses. The design experiments approach favors knowledge development through creating prototypes (that potentially represent multiple changes from previous version), using them in practice, and collecting insights [13], thus not sacrificing concrete, practical progress in the name of traditional research understanding.

Collaborative Inquiry

Throughout the larger effort described above, our team of five became acutely aware of the challenges we faced as individuals and a collective in attempting to utilize design thinking in a more traditional engineering course design context. Certainly there were successes, inspiring moments, and personal growth. There were also moments of doubt, conflict, and even despair as we considered our experiences and the potential to expand those experiences to our peers. Thus we decided to investigate the tensions we were experiencing in bringing design thinking to our distinct course design context.

We utilized a collaborative inquiry [15] approach to investigate the tensions we experienced and how they informed our application of design thinking in engineering course design. Collaborative inquiry is an experience-based and action-oriented [16] method for jointly investigating a topic of interest among an affinity group. In collaborative inquiry, members of the affinity group share responsibility and power for planning and engaging in the research [15,16]. Research involves repeated cycles of reflection and action, with each member of the team acting an equal participant-researcher.

Here, cycles of reflection and action fit into our established course design cycles. Reflection included informal discussions of course design thinking and tensions during regular course design meetings as well as more targeted discussions at separately scheduled, less frequent meetings. Action included engagement with design thinking at course design meetings and in our individual course design work as well as individual reflections outside of team reflections. The latter involved informal, self-initiated thoughts and writings as well as dedicated reflective writings agreed upon by the team at targeted discussion meetings. We engaged in these cycles repeated over several semesters, our individual and collective understanding evolving over time.

In preparation for this manuscript, we attempted to synthesize our evolving understanding through a four-stage process:

1) We discussed and gathered all writing, transcripts, and artifacts related to our discussions and design activities.
2) One author synthesized the data into a set of tensions.
3) We further engaged in a series of individual reflections and group discussions in response to the synthesis.
4) We collectively revised the tensions and discussion thereof to represent collective agreements and individual nuances.

Tensions

Here, we present five tensions we experienced throughout our engagement with design thinking in engineering course design. While our individual experiences and understandings varied to some degree, we present tensions as experienced by the team in a first-person plural voice, highlighting individual and sub-team nuances as appropriate.

Extant Course Design Culture vs. "Pure" Design Thinking

The first side of this tension refers to our course design context as we began our design thinking initiative. We came to the initiative with preferred course design practices, beliefs about design, beliefs about teaching and learning in engineering, and goals for future practice. Due to our different backgrounds, experiences, and perspectives, these practices, beliefs, and goals differed, but they were often well-established. We each had prior course design experiences. We each had successes and failures that had informed us. Further, we collectively were designing courses within well-established departmental, collegiate, university-wide, and field-wide contexts, which each carried specific expectations and constraints.

The second side of this tension refers to an honest desire to incorporate design thinking practices and mindsets into the way we designed our courses. While we all held different understandings of was design thinking was and might be in engineering course design, we all believed in the opportunity it provided and were open to enacting it as we redesigned two existing courses.

The tension arose when the practices and mindsets suggested by design thinking conflicted with either our prior course design practices and mindsets or contextual constraints of developing and implementing an engineering course. A key example of the former occurred in problem framing. Several of us were used to basing our course (re)design projects on content we hoped students would learn, activities we hoped to implement, or issues we noted with the way students interacted with the course. Design thinking suggested that, instead of focusing on our hopes and issues as designers, we should focus on identifying and addressing student needs while openly reframing as new understand came to light. A key example of the latter occurred in utilizing prototypes to experiment with new ideas. Design thinking suggested repeated cycles of developing and testing, often low fidelity, prototypes with users. Such cycles were often

challenging to enact at the scale of a semester and with limited opportunities to test lower fidelity implementations with actual users.

Unfamiliarity vs. Opportunity

The first side of this tension refers to the lack of familiarity some of us had with design thinking when we began this initiative. One of us encapsulated this with a series of verbal reflections about a month into the initiative, which we paraphrase below.

> I'm just becoming aware of design as its own discipline, complete with a body of research and practices. I'm aware of design from my engineering work and assuming this project wouldn't be too different from that. I'm learning that it is. It can be a bit intimidating.

Conversely, some of us were familiar with design thinking but unfamiliar of the potential disconnect with extant engineering course design cultures, as described in the above tension. Like our colleagues who assumed this new world of design thinking wouldn't be all that different from their own world, we neglected to consider the discomfort our colleagues might experience in engaging with this new world.

The second side of this tension refers to a belief that enacting design thinking would provide opportunities for each of us as individuals, our team as a collective, and even larger groups such as our department and other engineering faculty. These opportunities included, but were not limited to, engaging new and potentially more effective practices, developing novel and effective solutions (to challenging course design problems), learning from colleagues with different perspectives, and developing better connections to our students.

The tension arose when our collective unfamiliarity with design thinking in the context of engineering course design diminished our confidence in realizing the opportunities design thinking could provide. The design thinking novices among us would become apprehensive when engaging in new activities during design meetings. For example, diverging during ideation, an intentionally divergent activity, was a common challenge. In turn, the design thinking experts among us would struggle in finding ways to effectively engage the novices in new practices. We wondered, especially early on, what our struggles as a team meant for the future of design thinking in our course design practice, let alone the opportunities we sought to engage departmental colleagues or share our ideas with external faculty and researchers.

Ownership vs. Facilitation

The first side of this tension refers to the tendency for course instructors to take ownership of the course design process related to their specific courses. Part of this was habitual. While we each had previously collaborated, to some degree, with others in designing courses, we were used to taking responsibility for our courses each semester we taught them. We made key decisions. We determined how to implement them. We were responsible for course success. Although we engaged in a more collaborative process throughout this initiative, we respected each course instructors' autonomy and sense of responsibility.

The second side of this tension refers to the need for design thinking facilitation by one or more of the non-instructor members of the team. The previous tensions described nascency in design thinking expertise among some of us and the influence of prior practices and mindsets. Without providing structured activities and learning experiences, we could not guarantee authentic engagement with design thinking.

The tension arose when the need for process ownership among the course instructor conflicted with the suggested activities brought by the facilitator. In some cases, the course instructor would thoroughly interrogate the purpose and operation of the activity, leading to limited engagement with the activity or replacement with activities consistent with the instructor's prior practice. In other cases, instructors would bring other priorities to team meetings, subverting engagement with any facilitated activities. In still other cases, instructors would complete portions of course design work outside of the team. It should be noted that facilitators and others on the team frequently deferred to the instructor or even engaged in these three practices themselves.

Risk vs. Safety

The first side of this tension refers to the risks inherent in engaging in a divergent, iterative, and user-focused framework. Some of this risk exists at the course level, i.e., trying out big ideas and providing worse learning experiences for students. Some of this risk exists at the interpersonal level. By engaging in a new framework that contains substantive differences from our current frameworks, some of us risked backlash from colleagues or limiting opportunities to share that framework with colleagues. Some of this risk exists in working against student expectations for what a course or learning experience should be, thus limiting potential effectiveness of larger proposed course changes. Some of us also felt a risk of inauthenticity as a novice practitioner attempting to engage in design thinking.

The second side of this tension refers to the safety of taking small, manageable steps with both the integration of design thinking into our course design practices and attempting small, manageable changes to our courses, despite envisioning more substantive and effective changes. We had each achieved some level of success in our teaching. We each could have been proud of our work without taking the risks described above.

The tension arose in two ways. The first way was in-process, when we envisioned novel, large-scale course changes or more deeply engaged in the novel-to-us aspects of design thinking. We were often quick to consider potential risks described above. We frequently scaled back proposed course changes. The second way was realizing the negative side of risk upon implementing course changes or engaging in the process. We received pushback from several departmental colleagues related especially to the student-centered and innovation-focused aspects of our process. Further, some students demonstrated strong negative reactions to more substantive course changes, or smaller changes that did not align with their vision of engineering. For example, one student created a rude meme when one of us implemented a low stakes sociotechnical discussion in class.

Bandwidth vs. Sustainability

The first side of this tension refers to the substantive time and effort demands of faculty life. As faculty, we have research, service, and personal responsibilities beyond our teaching responsibilities. Design thinking activities such as empathizing with our users, reframing our understanding of their needs, engaging in divergent ideation and visualization, completing frequent prototyping cycles, and engaging diverse perspectives requires substantive time and effort beyond our typical teaching and course development efforts.

The second side of this tension refers to the structures that might support us and others in initiating and sustaining course design thinking efforts. Our initiative had many aspects in our favor, including salary support, deep engagement with collaborators, strong individual motivation to improve the state of teaching and learning, weekly meeting structures, and dedicated facilitation.

The tension exists in how we might sustain our efforts without such favorable conditions. For example, several of us have neglected to leverage many aspects of our collaborative design thinking work when working on individual courses outside the purview of the initiative. This has been true despite a desire to continue such engagement.

Navigating Tensions

Our experience of the tensions described above evolved as we engaged in the process. This does not mean that we resolved the tensions, either by striking a balance or embracing one of the poles. Instead, we engaged the tensions in different ways as our individual experiences and collaborations evolved. While we have not necessarily reached equilibrium, nor do we suspect such equilibrium is likely, we have learned to sit comfortably with the tensions. Rather than balance them, we navigate them. In turn, this navigation has informed our understanding of design thinking in engineering course design and how we can best enact it in our distinct circumstances. The following themes represent processes that supported us in navigating the tensions and informed our understanding and development of course design thinking.

Adapting Existing Tools to Our Needs and Context

The design thinking world has developed many tools and resources that can scaffold one's process and highlight relevant mindsets. These resources include templates, guided activities, expansive toolkits, and well-documented and flexible structures. We engaged a variety of tools across all aspects of our process, including tools to help empathize with students, focus on key user needs, ideate potential design concepts, and create and test prototypes within and outside of courses. Typically, the facilitator brought these tools to design meetings, we engaged in discussions (and often negotiations) around the tools' usage, we used the negotiated tools, and debriefed from the experience. In future iterations, the facilitator would adapt new variations on the established tools based on the unique needs of the team. For example, in a previous study, we documented and analyzed our use of personas, journey maps, and empathy maps to support our empathy for/with users and understanding of their needs [17].

Adapting tools was especially important to our navigation of the first three tensions. Regarding *extant course design culture vs. "pure" design thinking*, our collective negotiation of tool use and format allowed us to engage in practices consistent with design thinking, while imbuing those practices with aspects relevant to our more established practices and habits. Regarding *unfamiliarity vs. opportunity*, using specific tools and engaging with the facilitator regarding their purpose and functionality allowed the novices among us to become more familiar with and alleviate some discomfort with the novelty of design thinking while also creating tangible evidence of design thinking's utility (e.g., experiencing greater empathy for students after engaging in empathy mapping and journey mapping experiences). Finally, regarding *ownership vs. facilitation*, in adapting tools to our context, we leveraged the expertise of the facilitator in selecting, presenting, and guiding us through tool use while giving the course instructors among us more of a say in the process we followed.

Collaborative Reflection Cycles

A second key aspect of our practice was engaging in cycles of collaborative action and reflection. Our team met regularly, ranging from bi-monthly to twice per week, during all active semesters. These meetings focused on engaging in course design activities (often facilitated by our tool adaptations) ranging from explorations of the course context, review of design research on the courses and students, need finding, ideation of design problems and concepts, prototyping and evaluating selected concepts, and discussing the instructors' implementation efforts. We engaged in both micro-iteration cycles within individual meetings and macro-iteration cycles at key points in the design process.

Micro-iteration cycles involved a three-step process:

1. **Select practice or technique to engage** - One or more of the teams' design experts would propose a design activity or facilitate the team based on stated meeting goals from the course instructor. The proposal and facilitation relied on the team's current framing of design thinking in two ways: (a) it utilized a practice and/or technique that had been successful in past meetings or was a new practice/technique selected or adapted based on understanding of the team's engagement in past practices/techniques and (b) the framing of the practice or technique was meant to inspire targeted mindsets.
2. **Engage practice or technique** – The team would utilize the stated practice or technique with facilitation from the design expert. This often began with a discussion of the practice or technique, why it was selected, and its intended purpose. Team members often asked questions or offered modifications of the practice/technique to better suit their needs or comfort levels before and during its implementation. The design expert would also provide coaching during the practices' or techniques' use, especially as relevant mindsets were evidenced or not evidenced by the team members.
3. **Team discussion and reflection** - The team would reflect upon their experience and discuss any successes, dissonances, or challenges. These discussions, sometimes long and sometimes brief, led individual team members to internalize or question aspects of the design thinking and their individual enactment thereof and led the team to identify areas of success and challenge, as well as areas for future consideration.

The teams also engaged in macro-iterative cycles, which were segmented by larger and targeted team discussions based on either the end of a design cycle (e.g., end of semester) or when key insights or dissonance were evidenced. During such discussions, team members would share their understandings of design themes, observations of their and others' mindsets, and experiences engaging the practices and techniques. The goal of these discussions was to reach consensus on a shared vision of design thinking for engineering course design that could inform future work. These discussions helped us unearth the tensions described above and better understand our individual and collective experiences thereof.

Creating Visual Wins

A third key aspect was a result of the visual nature of design thinking. Many of the practices, tools, and mindsets of design thinking emphasize putting forth and developing ideas in a visual manner. This includes, but is not limited to, drawing new concepts and connections during ideation and other divergent activities; mapping knowledge, experiences, and understanding during user-related activities; and sharing ideas in immersive and visible ways. Such visual methods and, more importantly, outcomes provided a means for ourselves and others to gauge progress and internalize experiences and results, relating particularly to the *unfamiliarity vs. opportunity* and *risk vs. safety* tensions. For example, Figure 1 (below) demonstrates a journey map that represents student experiences and feelings of "connectedness" to the course based on proposed weekly operation of a course. This was created by team members role playing as a hypothetical student (often with different characteristics from oneself) and attempting to empathize with that students' experiences from week to week. The individual role playing experience provided critical connections and depth while the overall mapping allowed for broad perspectives with deep roots in that individual depth.

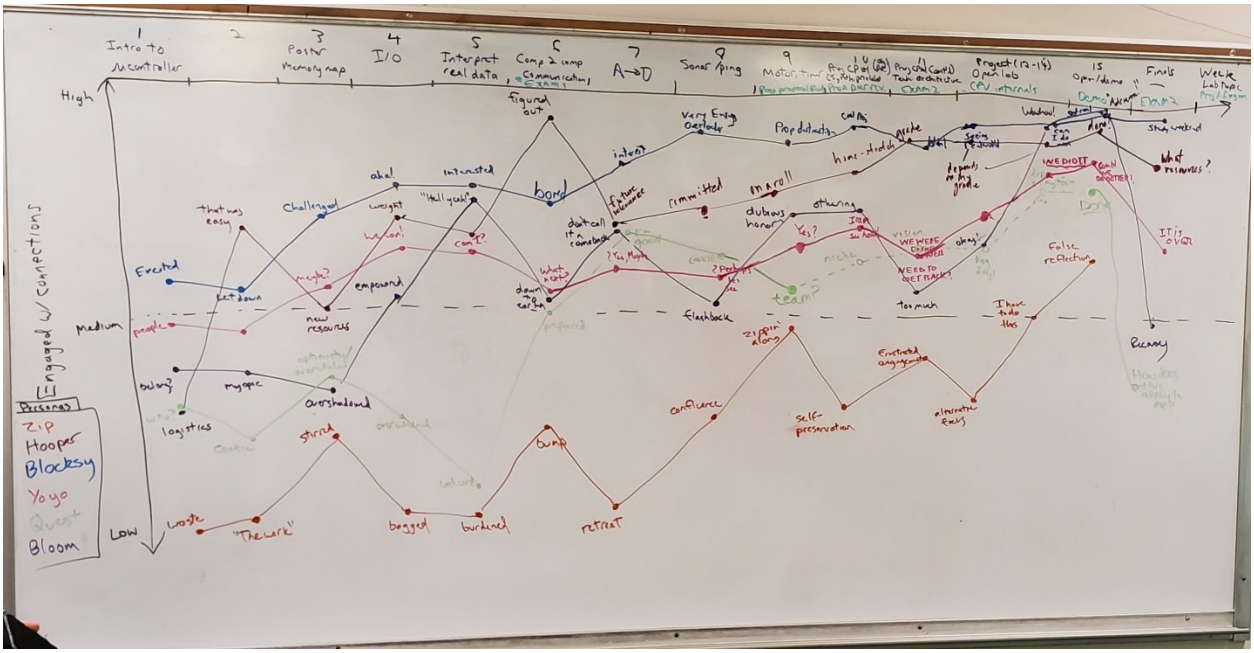

Figure 1. Journey Map Representing Students' Potential Experiences in Course Prototype

Such outcomes varied in scale throughout our process. At the smallest scale, visual whiteboard activities such as lotus blossom ideation, empathy mapping, journey mapping, drawing prototypes, and concept mapping provided visible outcomes of our process. One of us praised these outcomes as seeing our collective ideas come to life in ways they never thought possible. Such reactions provided key demonstrations of the opportunity side of the *unfamiliarity vs. opportunity* tension. At a broader scale, we often explored outcomes of our process in a visual manner. This included mapping course initiatives we'd developed, exploring student reactions and experiences, and even sharing outcomes, processes, and activities at departmental meetings. Through these means, we explored effects we'd had on students, courses, colleagues, and ourselves.

Concluding Discussion

In this collaborative inquiry study, we investigated tensions in the use of design thinking for engineering course design. These tensions collectively represented a dissonance between (1) the comfort, habit, and prior success of extant practices, mindsets, and culture in engineering course design and (2) opportunity for personal growth, academic innovation, and professional risk inherent in engaging new, user-centered, divergent, and experimental practices. In navigating these tensions, we came to a new understanding of ourselves, each other, and our processes. While we offer no concrete conclusions, we suggest that navigating tensions is an essential part of engaging in design thinking or potentially other novel engineering course design frameworks. This navigation allowed us to understand the importance of adapting and using tools and resources, participate in collaborative reflection cycles, and create visual wins. Further, it brought us to an emerging adaption of design thinking, informed by extant engineering course design practices and mindsets but imbued with key aspects of design thinking, which we refer to as *course design thinking*. In the future, we plan to continue unpacking, understanding, and communicating course design thinking through research on specific aspects, research in additional contexts, and the development of an interactive, evolving toolkit for educators and researchers alike.

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