Design Thinking as a catalyst for changing teaching and learning practices in engineering

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***Abstract*—Today's engineers' needs are evolving rapidly as the information and technologies that compete for their attentions. At the same time, our institutions and systems are stretched to their limits to keep up with the changing demands of the times. There is, especially, a need to sustain reflective integration of social and technical knowledge into the future generations of engineering, to make engineers more humane, in order for them to generate technological solutions that are more human-centric. Addressing such needs requires new approaches to teaching and designing engineering courses. Any advancement in the education sector from here forward requires a new thinking paradigm that can be applied in large-scale systematic reform of education: design thinking. This paper outlines means to use design thinking as the foundational methodology for transforming a traditional electrical and computer engineering department into an agile department where design thinking, systems thinking, professional skills and inclusion are promoted, and collaborative, inquiry-driven processes are stimulated to create and sustain new ways of thinking, interacting, teaching, learning and working.**

Keywords—design thinking; heutagogy; X-teams

I. Introduction

Many academic organizations are calling attention to the need for urgent changes in curricula and learning methods required for continual social transformation of an increasingly technological world. Transversal skills such as the ability to think creatively and critically, take risk and initiative, and work collaboratively are essential to guarantee a qualified workforce to adapt to this transformation. Many recent publications by academics, practitioners and even government organizations, claim that design thinking has the power to stimulate these social competences and to drive innovation in organizations and education [1-15]. Design thinking is more than a model for innovation. It refers to a combination of mindsets, processes and toolkits that help people build empathy within the context of the problem, creatively generate insights and solutions, and rationally analyze and execute solutions for the same context [16].

In this work, design thinking will be promoted (1) for cross-disciplinary faculty members (X-teams) as they redesign their courses and the overall pedagogical approaches, and (2) for students as part of their professional formation. X-teams will be created through bringing electrical and computer (ECE) faculty together with engineering education and design faculty, industry practitioners, context experts, instructional specialists and teaching assistants. The goal is to facilitate an iterative process of assessing current practices and proposing new teaching and learning approaches, collectively, by including various stakeholders. X-teams will take the ownership from the primary instructor and use design thinking and reflection practices to explore novel pedagogical strategies.

II. Design Thinking

Design thinking is a user-centered process that starts with user data, facilitates designing artifacts that address real user needs, and ensures that artifacts address those needs by testing them with real users [1, 17]. It leverages collective expertise and establishes a shared language among team members while encouraging innovation through multiple explorations of the problem and solution spaces. Although it has six phases [18, 19] that help navigate the development from identifying a challenge to finding and building a solution, each phase is meant to be iterative and cyclical as opposed to a strictly linear process. Design thinking, despite originating in the domain of design, has seen transition from design education and practice to its new interpretations and implications for business, engineering, education, and other disciplines, as it is associated with a methodology for solving wicked problems beyond design. However, even though design thinking has been practiced with enthusiasm, there has been very little empirical evidence suggesting benefits of its use in diverse contexts. Thus, one key aspect of this project is to explore how design thinking can best be used to restructure engineering teaching and learning.

In this work, we aim to adapt Evolution 6^2 model (Emergence, Empathy, Experimentation, Elaboration, Exposition, and Extension) [18, 19] for instructional design and provide an overview of the type of cross-disciplinary instructional team we are forming, how we plan to train them, and the study we will conduct to evaluate the impact of using design thinking in this novel setting. The model suggests that the creative process is evolutionary and iterative allowing a strong integration among the participants and the phases. Since there are moments of Exploration (divergence) and Evaluation (convergence) in every phase of the model, we will also describe our inquiry on how these moments fold into each other in a departmental culture shift.

III. Teaching Practices

X-teams will reshape core technical ECE curricula in the middle years through novel and proven pedagogical approaches that (a) promote design thinking, systems thinking, professional skills such as leadership, and inclusion; (b) contextualize course concepts; and (c) stimulate creative, socio-technical-minded development of ECE technologies for future smart systems, including security and privacy. Using the iterative design thinking process and reflection, the teams will explore professional formation pedagogy (PFP) strategies and integrate them into courses.

There are many approaches that define the characteristics of design thinking, such as tolerating ambiguity, viewing design as an inquiry, maintaining the vision for the big picture through including systems thinking, and handling decisions and thinking as part of a team [20]. Each of these characteristics require an important attribute: effective inquiry. Effective inquiry in design thinking includes both a convergent, analytical and systematic reasoning and divergent reasoning that would facilitate generative design questions. However, in current engineering education curricula, the focus is mainly on convergent approaches in which the primary objective is the formulation of a set of deep reasoning questions with the goal of obtaining ‘the’ answer. How can effective inquiry, the systematic interplay between divergent and convergent thought processes, be taught as essential and integral to engineering education?

IV. Research Study On Teaching Practices

Our goal is to illustrate that design thinking could provide a robust process for restructuring both teaching and learning experiences. Dym [20] has suggested means to integrate design thinking into the existing engineering curricula, such as: Can the exam questions be designed in a way that the students would be required to generate concepts by asking generative questions and then offer solutions based on deep reasoning questions?

To create an initial understanding of the design thinking mindset, process and toolkit, the project team was introduced to design thinking through a one-hour workshop. The workshop was developed using Stanford d.school’s model on introducing design thinking to non-designers [21]. The workshop described design thinking with a focus on its iterative, collaborative process while asking the faculty members to integrate the process steps to design the perfect wallet for each other. This quick overview of the entire process asked the faculty members to sketch their ideal wallets, interview their partners to gather insights, define a point of view based on these insights, sketch alternatives based on these insights, test them with their partners and gather feedback, and build a physical prototype using this feedback.

Although a simple introduction, this exercise demonstrated some key tenets of the design process, including its iterative, user-centered and prototype-focused cycle. It also allows the participants to see the value of engaging with real people, that low-resolution prototypes are useful to learn from, and to bias toward action [21]. Our next step is to adapt this workshop for specific X-teams, in order for them to explore how one of the targeted ECE courses could be redesigned.

Some of the research questions to be investigated in these workshops are:

- How can we leverage divergent and convergent practices in the design thinking thought process to develop better pedagogical approaches for engineering education?
- What are the best practices for getting engineering students to own their own education? What support structures are needed? How does design thinking facilitate these practices?
- How can we develop students to be active knowledge seekers instead of information receivers, and how does design thinking play a role in this transition?

These questions will be explored in detail during faculty development workshops at the beginning and end of each semester. The outcomes of these workshops will be collected as a set of guidelines to inform the faculty as they restructure their courses and students’ experiences. Each outcome will highlight the potential with provocative statements focusing on potential opportunities in a narrative format. These narratives will tell an engaging story, describe the feedback collected from the pedagogical prototypes evaluated, and communicate the value. A scenario for the workshops is illustrated below:

1. <u>Emergence:</u> Faculty members and a select group of students and stakeholders gather to discuss the skills necessary for the students to succeed in the future.
2. <u>Empathy:</u> The group synthesizes the discussion to create a series of questions, such as, “how might we provide opportunities for learning about responsible development?”
3. <u>Experimentation:</u> The group generates a diverse range of ideas that will include tools and processes that can be used in the curriculum.
4. <u>Elaboration:</u> The team prototypes several of these ideas about teaching and learning approaches and creates a vision for short and long-term plans in order to continually build out this approach over time.
5. <u>Exposition:</u> Solutions are put into storyboards, illustrations, vision statements for presenting to a broader audience.
6. <u>Extension:</u> Many of these solutions that will integrate project-based-learning in the classroom and to create a different learning and teaching environment will be tested. There will be dedicated times in the faculty meetings to reflect on the experimentation and learn from each other.

In addition to interviews, observations and the data collected through workshops, we will use heuristics theory as the foundation to explore *Instructional Heuristics* practiced by X-teams. The term “cognitive heuristic” was developed in the field of judgment and decision making to refer to the cognitive “short cuts” people use in complex problem finding and solving [22-26]. ‘Heuristic’ is a term used in many domains; for example, Moustakas [27] described a heuristic methodology as a systematic form of qualitative research, Ulrich [28] proposed heuristics used in system evaluation, Riel [29] identified heuristics for computer scientists, Koen [30] described the engineering method through the heuristics he observed, and Nielsen [31] used heuristic in evaluation of interface usability. These approaches from different domains share the goal of the identification of cognitive strategies based on past experience that lead to quick, but not necessarily “correct” solutions.

Our goal is to document how educators involved in the X-teams use design thinking to explore means to change the structure of the existing curricula to create new opportunities for new pedagogical solutions. Through analysis of interviews and observations of educators’ practices, and newly created teaching materials, we will extract and characterize the heuristics that are successful in (a) building X-teams with faculty from diverse educational backgrounds, (b) implementing design thinking principles in creating new teaching approaches to existing content, and (c) assessing student performances from a new lens. The findings of this research will provide the basis for new pedagogy and will be used as one of the key elements for disseminating our experience throughout the process of revolutionizing our department and will create opportunities for other educators to use these heuristics in their own organizations to transform their curricula.

V. Learning Practices

There is a certain need to move from andragogy towards self-determined learning, a concept called heutagogy [32]. Heutagogy is the study of self-determined learning with an emphasis on learning ‘how to learn’ as a fundamental skill. Rogers [33] and Graves [34] suggest that teaching has to be taken from a teacher-centered approach and completely shifted to a student-centered approach. This argument highlights facilitating learning instead of direct teaching and makes the student responsible for the maintenance or enhancement of the learning structure. In heutagogy, the learner is seen as highly autonomous and focused on the development of one’s learning capacities. In this process, educators function as facilitators or coaches in the knowledge-creation processes, instead of being knowledge providers as is the traditional education systems.

Because of its human-centeredness and experimental approach, design thinking offers huge potential in transforming the traditional learning system into self-determined learning. Heutagogy suggests that learners are ‘problem-finders’ which is also essential for design thinking. Even if problems are provided, design thinking provides guidelines on how to critically question the problem and explore its underlying factors. Heutagogy requires the learners to take the responsibility for their learning and welcome challenges, which matches well with design thinking’s emphasis on failing early and fast through iterative prototyping throughout the process. It also suggests that learners are enquiry driven, seeking further complexity and uncertainty, which is also an essential element in design thinking. With every new test or piece of feedback, students identify new complexities. Design thinking puts the emphasis on developing possibilities rather satisfying constraints.

VI. Research Study On Learning Practices

Classroom experiences will be redesigned by interviewing the students who previously took the courses and developing new curricula around the data collected. This data collection will also be an iterative process where human-centered design techniques will be embedded to understand how to engage students more in their learning. This process will include generating a series of potential ways to deliver the topics (divergent thinking) and combining and synthesizing them into practical means to integrate into the curricula (convergent thinking). As design thinking requires a creative act supported by reflections at every stage, X-teams will become the designers of these courses, which will change the perspectives of the course instructors in creating new pedagogical materials. As the students will be highly involved in this process, this approach will give ownership of the course to the students and seed the entrepreneurial thinking that will impact students’ thinking processes as they approach their careers. A scenario of implementing design thinking process to a student-centered learning setting can be illustrated as below:

1. <u>Emergence:</u> Students identify an opportunity within the problem domain, find the need why the problem has to be solved and who will be the immediate beneficiary.
2. <u>Empathy:</u> Students then choose a stakeholder who is affected by the issue to share their experiences. They interview them, map their context, and create journey maps and personas to build empathy.
3. <u>Experimentation:</u> Students review the stakeholder stories and generate a diverse range of solutions targeting the potential opportunities.
4. <u>Elaboration:</u> Students evaluate the solutions through matrices and cluster analysis and rapidly prototype the most promising solutions, role play how their solution would be integrated and used, and pilot test them with the stakeholders to gather insights. Students improve their solutions based on the insights.
5. <u>Exposition:</u> They then present, communicate and demonstrate these advanced solutions to various stakeholders for feedback, using storyboard, prototypes, illustrations, and presentation boards.
6. <u>Extension:</u> Students test the solutions, observe their use, and reflect on the next steps and lessons learned.

Helping students to think like designers of their education and practices may better prepare them to deal with difficult situations and to solve complex problems in their education, career, and in life in general. Enhancing students’ design thinking skills may be achieved through incorporating authentic and intriguing tasks into the classroom and providing many opportunities to apply design processes. As students provide information on their tasks, evidence will be cumulated to evaluate their performance. Such information will help educators monitor students' strengths and weaknesses relative to design thinking variables, and provide targeted feedback to improve their performance.

One of our major goals in this research program is to collect good evidence of design thinking skills on learning and design and develop accurate, competency and performance-based measures of these skills. For developing such assessment tools, we will employ the evidence-centered design framework (ECD) [35]. This conceptual design framework supports a broad range of assessment types from familiar standardized tests and classroom quizzes, to coached practice sessions and simulation-based assessments, to portfolios and student-tutor interaction [36]. Using this framework as the foundation, we will develop a systematic approach to assess design thinking skills used in various tasks, learning and teaching practices, student-educator interactions, and the outcomes and deliverables throughout the targeted four ECE courses. Through adapting the competency model, we will investigate key questions, such as:

1. What are the effects of the design thinking process on various learning outcomes?
2. How does design thinking mediate the learning process? For example, we can relate problem-solving skills to certain characteristics of design thinking which then can be related to increases in exam scores?
3. How is the design thinking process used to help interdisciplinary collaboration in curriculum development and teaching and learning practices?

VII. Conclusions

To prepare our students for the 21st century challenges based on the rapid-changing technological advances and the societal changes, we should provide them with opportunities to interact with content, think critically through reasoning and analysis, and use it to create new information. Having strong design thinking skills can assist future engineers in adjusting to unexpected changes and facilitate roadmaps to success through reframing the problems, experimenting with solutions, and skillfully applying the iterative design process in any situation. But these student outcomes require rethinking the way we structure engineering teaching and learning.

This paper has outlined an approach to use design thinking as a foundational methodology to transform engineering departments to support such outcomes. This approach will feature cross-disciplinary and cross-functional X-teams, who will jointly assess current practices and propose novel teaching approaches. This approach will also transform the way engineering students interact with their education. Here, students will become more involved in their learning environments, both as engaged stakeholders of the X-teams and active participants in new systems of self-determined and inquiry-driven learning. Through rigorous research on the X-teams' practices and the new learning environments they help construct, we will continue to improve the design thinking approach to educational transformation and disseminate results to support similar transformations at other institutions.

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