WIP: Using a human-centered engineering design mapping tool to inform ABET accreditation for an existing engineering design program

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Introduction

Integrating human-centered design (HCD) in engineering, such as through a "human-centered design and engineering" major, has gained ground in recent years. Select universities across the nation offer some form of human-centered engineering design (HCED) or closely related fields such as human-centered engineering or human-computer interaction. For example, the University of Michigan-Dearborn has a human-centered engineering design major [1] and the University of Washington has a human-centered design and engineering program [2], both for undergraduate students. Similarly, Dartmouth Engineering offers a human-centered design minor [3] and Boston College recently launched a new human-centered engineering program [4]. Ongoing work within the field of engineering education seeks to continue promoting and offering these types of programs with the overarching goal of equipping engineering graduates with both objective, or "hard," and subjective, or "soft," skillsets [e.g., 5, 6] – in other words, equipping them to apply a human-centered perspective in the workplace.

Although these programs are on the rise, they are relatively young. Furthermore, ongoing discussion in the field debates how best to teach human-centeredness in engineering design. It follows that ongoing research should investigate human-centered design pedagogy in engineering education. Our research has focused on integrating human-centered design within engineering curricula with the goal of producing more capable engineers who can navigate both technical constraints and user needs. Doing so has included supporting collaborative course development efforts, for which we developed tools and resources. More recently, we applied one of our tools to an existing HCDE program to explore the ability to track competency development at the program level. In this paper, we discuss our collaborative efforts, and preliminary results from, using the HCED mapping tool to visualize competency development.

We are an interdisciplinary design team that is composed of faculty from the University of Washington and researchers at the Siebel Center for Design (SCD) [7] at the University of Illinois Urbana-Champaign. Since 2019, SCD researchers have been using HCD to develop programs and design activities that can help students learn about HCD processes and practices and develop its mindsets [8]. This team is associated with the Human-Centered Engineering Consortium (HCEC) [9], a community of leaders and educators dedicated to advancing the field of human-centered engineering.

Background

Human-Centered Design in Engineering Education

In previous work, we developed a framework that describes "human-centered engineering design," or the integration of human-centered design within technical engineering design [10]. We used literature to compile evidence for what HCED looks like in practice. In essence, practicing HCED means engineering for people and with people. Engineering for people includes practices such as maximizing stakeholder involvement [11], prioritizing problem identification and framing in the context of stakeholder needs [12], considering societal, economical, and environmental design impacts [13], and considering ethical design impacts [14]. Engineering for people includes maximizing stakeholder involvement while also promoting collaboration among design team members [15] and emphasizing well-being and care [16, 17]. Furthermore, engaging students in HCED practices connects to constructivism, experiential learning, and situated learning [18]. Engagement in HCED can prepare students for a diverse, collaborative workplace and help them to balance technical and subjective design decisions [19] as well as develop 21st-century skills and mindsets critical for success in both academia and industry [20].

Interdisciplinary Course Development Efforts

HCED Mapping Tool. In previous work, we partnered with engineering faculty to develop an HCED mapping tool [10]. We have used this tool in the form of an interactive worksheet with faculty to support course development efforts by mapping opportunity areas for HCED activities, including relevant student learning outcomes, and aligning them with current coursework. Our ongoing work has documented these efforts, which have taken place in required courses in four-year ABET-accredited engineering programs. Our efforts have focused on supporting ABET's student learning outcomes among other relevant, broader frameworks such as KEEN's entrepreneurial mindset [21] and literature-based human-centered design mindsets [8].

Competency Development. More recently, we collaborated with faculty in a four-year aerospace engineering program to create a version of the mapping tool that focuses on students' competency development at the program level [22]. As part of this work, our interdisciplinary team advocated for the use of strategic learning progressions that map opportunity areas for students to develop predetermined competencies throughout a four-year program. Tracking students' development of program-specific competencies can serve as formative assessment toward their achievement of program educational objectives (PEOs). In monitoring students' progress throughout the program, individual courses can serve as intervention points that improve students' development. While it is unrealistic to expect that every course supports every PEO, we argue that a good program design leverages its courses to collectively engage students in achieving all PEOs. Thus, identifying opportunity areas helps to visualize where in the program students can reasonably be expected to engage in developing each PEO-related competency (or skill set), and performing formative assessment can verify that students are engaging in these opportunities.

Current Efforts: Program-Level Competency Mapping to Support ABET Accreditation

We then collaborated with external faculty from the University of Washington (UW) to use the mapping tool in a new way: to support a human-centered design and engineering program in pursuing technical ABET accreditation. We mapped ABET student outcomes to required courses in the program, which is one step in the course development process for integrating HCED. However, instead of doing this to identify opportunity areas, our goal instead was to develop a map to provide evidence of continuous improvement (ABET Criterion 4). This meant that we needed to scale from investigating course-level learning outcomes to understanding how these outcomes impact students' development of program-level competencies.

Furthermore, in addition to using the mapping tool for programs in which required courses are prescribed in a linear sequence (a cohort model), we applied it to the alternate format used by this particular program, in which students craft course sequences such that they fulfill all required courses by the time they graduate. Our process included interviewing faculty about required courses to understand which student outcomes are met and how they are assessed. Members of the research team synthesized the interview data by mapping evidence related to a set of program-level student competencies to visualize where in the program students find opportunity to develop each competency.

University of Washington HCDE Program Format

The University of Washington offers a human-centered design and engineering program [2] that is currently preparing for ABET accreditation under the ABET Engineering Accreditation Commission (EAC). Our interdisciplinary team has been working to map PEOs across all required courses to identify where students should be engaged in developing each PEO-related competency and how that development is currently assessed or should be assessed. We present here a brief case study of our efforts and results so far and discuss meaningful takeaways from the process.

UW engineering students complete core science and mathematics courses prior to entering the two-year HCDE program. Once in the program, students must complete a set of 10 required 300-level courses as well as satisfy a minimum of 23 credit hours from 400-level electives. The program also includes a two-course Foundations Sequence and two-course Capstone Sequence. Courses are offered by academic quarter, meaning that students have three quarters per academic year and two years to complete their requirements. The program largely grants students the autonomy to complete their courses in an order of their choosing, though some courses have prerequisites.

Methods

To develop preliminary insights regarding the HCDE program, members of the research team reviewed current course information, such as syllabi and project materials, and engaged in discussion with faculty to further explore the program's current offerings and efforts to seek accreditation. The team's exploration included reviewing PEOs and using them to develop a potential set of competencies that students should develop as a result of engaging in the required courses. The PEOs and corresponding drafted competencies are listed in Table 1; these will be further refined during ongoing work.

Table 1. HCDE PEOs and Student Competencies

PEO: Students will….	Competency	Reference Number

… demonstrate knowledge of human-centered design and engineering principles.	Understanding of HCDE	1
…apply empathy to design processes and user research.	Application of Empathy-Related Processes	2
…use iterative processes to refine and improve designs.	Application of Iteration-Related Processes	3
…explain core concepts and principles of user experience design.	Understanding of User Experience	4
…apply engineering science and design principles to problem-solving.	Application of Engineering Science & Design	5
…recognize the role of communication and collaboration in team-based projects.	Awareness of Communication & Collaboration Skills	6
…use effective communication and collaboration skills in professional contexts.	Application of Communication & Collaboration Skills	7
…exhibit professional skills and ethical responsibilities in design practices.	Professional Skills & Responsibilities	8

The team then interviewed faculty about the required course(s) they recently taught or currently teach to understand which ABET student outcomes are met by the courses and how they are assessed. The interview protocol is provided in the appendix; all interviews were recorded and transcribed. All 10 required 300-level courses were discussed and two 400-level electives were discussed. Members of the research team synthesized the interview transcriptions by mapping evidence related to a set of program-level student competencies to visualize where in the program students find opportunity to develop each competency. The mapping structure, with example insights from a prototyping techniques course, is depicted in Table 2.

Table 2. Program Mapping Structure with Example

			Human-Centered Design and Engineering Competencies							
Required Courses			1	2	3	4	5	6	7	8
Course #	Course Title	**Description →**	Analyze different design scenarios and make an argument for appropriate prototyping and evaluation techniques to use.	Organizing principle for the final project is that it's related to the UN Sustainable Development Goals.	Every assignment is about designing, creating and building the prototype of a tool or system.			Write-up during analysis phase should clearly communicate the ”why”—why a particular design idea, technique, or how the technique helped students to do the design evaluation.	Collaborate on design project and communicate project with audience.	
		ABET EAC Outcomes →	2	4	6			3	3, 5	
		Performance Indicators →						Students complete written analysis.	Students participate in their project teams. Students communicate project updates and findings with audience.	
		Assessment →							Process log Process portfolio	

During the synthesis process, the boxes in each competency column in Table 2 were populated with information from the interviews and other data sources according to the subcategories (i.e., a description of the course), ABET student learning outcomes that connect to the course's learning objectives where applicable, potential performance indicators, and assessments associated with the performance indicators. It is important to note that these competencies serve as a way of articulating the goals of the program in terms of specific capabilities students can demonstrate. They are aggregations of student learning outcomes.This is in contrast to program educational objectives, which express broadly what a student should be able to attain within a few years of graduating.

Findings

Brainstorming Performance Indicators

Once compiled, the research team discussed the chart and used the performance indicators, assessment methods, and relevant ABET outcomes reported by faculty to draft a master list of performance indicators that could be applied to students as they participated in the program. These were organized in relation to each ABET outcome and program-related competency. Table 3 provides the list.

Table 3. Drafted Performance Indicators Mapped to ABET Outcomes and Competencies

ABET Outcome	**HCDE Competency**	**Performance Indicators**
SO1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.	1, 5	1a. Can the student formulate and solve an engineering problem using human-centered design processes?
		1b. Can the student build a technical system consisting of software and/or hardware to support human interactions?
SO2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.	1, 2	2a. Can the student frame a human centered engineering problem using needs-based factors?
		2b. Can the student articulate the social and cultural characteristics that impact upon the design of a technical system?
SO3. An ability to communicate effectively with a range of audiences.	6	3a. Can the student use oral communication skills to frame a subject, and present an argument to a target audience?
		3b. Can the student write in a technical style with appropriate use of graphics, grammar and mechanics?
		3c. Can the student prepare data graphics to present the results of research and data analysis?
SO4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.	7	4a. Does the student identify ethical dilemmas in engineering scenarios and justify decisions using professional codes of ethics and ethical principles?
		4b. Can the student assess how engineering decisions impact global and societal contexts, including cultural, political, and economic factors?
		4c. Can the student evaluate the environmental sustainability and economic feasibility of engineering solutions and recommend actions that consider long-term consequences?
SO5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.	7	5a. Does the student share equitably in the management and execution of team assignments?
		5b. Does the student demonstrate effective time management and project planning skills?
		5c. Does the student contribute to a collaborative and inclusive environment?
SO6. An ability to develop and	3, 4	6a. Can the student design and implement user testing to evaluate

conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.		system design requirements?
		6b. Can the student process and analyze data to evaluate technical systems?
		6c. Can the students make design recommendations based upon analysis of findings from user and system data?
SO7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.	7	7a. Given a human-centered design objective, can the student independently research, and critically evaluate how others have tried to achieve that objective in the past?
		7b. Given a problem with incomplete information, can the student fill in the knowledge gaps in order to solve the problem?

As this process is iterative and ongoing, we are currently working with stakeholders to determine the accuracy and relevancy of the performance indicators.

Limitations

As our process relies heavily on insights from faculty, individual availability imposed a limitation on the extent of information we could compile. Furthermore, there were many uncontrolled variables that could impact the quality and consistency of information gained during the interviews, such as faculty members' seniority/experience with their course and varying assessment strategies across courses. The process of synthesizing findings and validating them with stakeholders also requires a time investment.

Takeaways and Next Steps

First, these efforts demonstrate that competencies can be mapped and tracked regardless of whether all students take required courses in the same order. In terms of continuous improvement for engineering programs, this strategy can assist in assessing a sample of courses by using identified competencies and performance indicators as the guidelines for course selection. For example, in our case, administrators could sample the subset of courses that are identified as supporting students' development of competency #1, using the performance indicators connected to that competency. Similarly, administrators could sample the subset of courses that support students in achieving ABET learning outcome #5. Thus, program-level assessment procedures can be guided by desired student learning outcomes, as opposed to revealing student learning outcomes across courses as a result of the assessment process.

Second, the ability to map students' competency development within a program space can support accreditation needs and continuous improvement efforts for engineering programs. In showcasing our method, we highlight the importance of strategic program development for the continual evolvement of engineering education.

Next steps for this work include continuing to work with and receive feedback from program stakeholders as well as reviewing and refining the set of proposed performance indicators. Future work also includes sampling a subset of required courses to confirm the finalized performance indicators.

Conclusion

Our interdisciplinary team applied our HCED Mapping Tool to a human-centered design and engineering program to map a set of competencies across required courses in the program. Doing so visualized opportunity areas for students to develop each competency, which led to brainstorming a set of performance indicators to assess the development of each. These efforts were made to support the program in seeking technical accreditation. The HCED Mapping Tool that was applied at the program level has also been applied at the program- and course-levels in technically accredited programs to explore the implementation of strategic learning progressions and identify opportunity areas to integrate human-centered design, respectively. This work seeks to support strategic program design in engineering education toward the goal of graduating engineering students who can navigate and balance process constraints with user needs, which better prepares them to navigate the diverse and complex modern engineering workplace in a productive and mindful way.

Appendix

Interview Questions:

1. Can you briefly describe the ways in which you are involved in the HCDE program?
2. Can you give a brief overview of what this course covers?
3. On average, how well do you think students achieve this learning objective?
4. How does your course support students in achieving this learning objective? (e.g., describe activities, requirements, assignments, etc. that connect to it)
5. In your opinion, why is this learning objective important for students to learn?
6. (if needed) How do you support students in developing communication skills? How do you support them in developing collaboration skills?
7. What are some measures you currently have in place to evaluate students’ progress toward achieving these learning objectives?
8. Let’s think about students’ skill levels. What skill level do you think students bring to the course? (e.g., beginner or naive, intermediate, informed)
9. What skill level do you feel students leave the course with? Why do you think this?
10. Besides lecturing, in what ways do you interact with students? (e.g., office hours, in-class project time, etc.)
11. What are some supporting tools that you incorporate to enhance student learning? (e.g., computing resources, laboratories, etc.)
12. What are your future goals for the course?

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