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WIP: The Impact of Human-Centered Design Modules on Students' Learning in an Introduction to Electronics Course

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Introduction

Human-Centered Design (HCD) is a problem-solving approach that uses design thinking tools to identify the unmet needs of a population in order to collaboratively and iteratively develop meaningful and innovative solutions [1]. Research studies continue to show that engaging higher education students in HCD experiences can positively influence their development of 21st century mindsets such as human-centeredness, metacognition, collaboration, communication, creativity, and experimentation [2]. These mindsets match what current employees seek in employers [3]. Consequently, many universities are supporting the integration of human-centered design and design thinking in their courses as one way to prepare their students to succeed in future workplaces [4].

For higher education engineering students, research studies continue to provide evidence that engaging students in HCD experiences have a positive impact on learning outcomes [5]. These outcomes overlap with those set by ABET's accreditation criteria that outline engineering graduates' outcomes for engaging in the professional practice of engineering [6]. Nevertheless, the field still lacks empirical studies that describe how HCD activities are designed and integrated in existing higher education engineering courses, then measure the impact of these activities on students' learnings. Findings from these studies can promote efforts of scaling the integration of HCD in existing higher education engineering courses by enriching our knowledge on possible models of integration and the impact of these models on students' learning.

Human-Centered Design and Engineering

Human-Centered Design is a problem-solving approach that uses design thinking tools to identify the unmet needs of a population in order to collaboratively and iteratively develop solutions [1]. It provides a flexible structure for solving wicked, ill-structured challenges [7] and generating creative and meaningful solutions [8]. HCD centralizes humans in the design journey through emphasizing with stakeholders, understanding them, and collaborating with them to explore and define problems [9], [10]. Then, HCD engages the stakeholders in iterative cycles of prototyping, testing, and reflecting to develop and sustain solutions [1]. HCD involves practices such as documenting biases and assumptions, interviewing people, identifying themes, communicating ideas, creating low-fidelity prototypes, and developing plans to bring final designs to the market [11].

Given HCD's effectiveness in solving complex, ill-structured problems, education researchers advocate for integrating HCD in higher education curricula [2], [12]. Supported by constructivism and experiential learning theories [13], they argue that students can benefit from learning about and implementing HCD practices to become lifelong learners and problem solvers [14], [15]. As students apply HCD, they use their prior knowledge and experiences to find and critique resources, create evidence-based arguments, build and test models, present ideas, manage time, and work in teams [16], [17]. This eventually can help them develop human-centered, metacognitive, collaborative, experimental, creative, and communicative mindsets [15], [18]. These mindsets match with what employers seek in 21st century employees [3] and thus, developing these mindsets during higher education programs can better prepare students for success in their future careers.

In light of the potential positive impact that engaging in HCD practices can have on students' learning, universities are increasingly investing in integrating HCD in their existing programs [4]. In engineering, learning about and implementing HCD practices can be viewed as means for students to achieve the outcomes that are listed in the ABET accreditation criteria [5] and can prepare students to enter the professional world of engineering [19]. For example, during HCD activities, students may work in teams to solve a design challenge which eventually can impact students' "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" [6]. Another example is students engaging in practicing and preparing oral and written presentations of the HCD outcomes to different audiences which eventually can impact their "ability to communicate effectively with a range of audiences" [6]. Besides, HCD approaches to design in engineering can lead to innovative and creative designs; it can also increase productivity, improve quality, minimize errors and development costs [20]. Therefore, the role of HCD is critical to the engineering design process and cannot be viewed as a separate process or outcome of the engineering design process [21]. Nevertheless, integrating HCD in existing engineering programs is challenging because we are still in the process of designing and evaluating evidence-based tools that can be effective in fostering students' understanding of HCD and its role in engineering, and development of skills associated with HCD mindsets and are directly connected to the ABET students' outcomes. The field still needs research studies that adopt a design-based approach to design, implement, and evaluate different ways of integrating HCD in existing engineering courses. Findings from these studies can provide insights for instructional designers and curriculum developers on evidence-based tools that can assist instructors to teach about HCD and can facilitate students' understanding of HCD and its role in engineering, and development of skills associated with HCD mindsets and are directly connected to the ABET students' outcomes.

The Purpose of the Current Study

This Work-In-Progress study describes and evaluates the design and integration of HCD modules into an existing Introduction to Electronics course. The engineering course introduced students to selected fundamental concepts and principles in electrical and computer engineering through virtual lectures and laboratory sessions. Two modules that aimed to 1) engage students in learning about human-centered design and its role in engineering and 2) engage students in team-based discussions and storytelling activities were designed and integrated in two laboratory sessions. This study answers the following research questions:

1) What is the impact of these modules on students' understanding of HCD and its role in engineering design?

2) What is the impact of these modules on students' knowledge of performing the HCD processes associated with completing the engineering design challenges in this course?
3) What is the impact of these modules on students' development of skills associated with the collaborative and communicative mindsets?

Methods

Design

The study adopts a design-based research methodology [22] to design, implement and evaluate two human-centered design modules in an introduction to electronics course. The study uses mixed methods [23] to measure the impact of integrating these modules in the course on students' understanding of HCD and its role in engineering design. The study also measures the impact of the modules on students' knowledge of performing the HCD processes that aim at understanding an engineering design problem and students' development of skills associated with the collaborative and communicative mindsets.

Participants

The study focuses on the students of an introductory electrical engineering course in Spring 2021, taken primarily by first-year electrical and computer engineering students. The course serves as a basic introduction to basic electronic circuits and how to build them. In addition to three hour-long lectures each week, students in the course attend a weekly three-hour laboratory session, where they work on a series of guided projects exploring topics they are learning in lecture using components in a personal required lab kit. In past semesters, the final project of the course has been an open-ended design project where students are encouraged to create something using the concepts learned throughout the course. However, curricular limitations as a result of the ongoing COVID-19 pandemic have forced the final project to be narrower in scope compared to the past two semesters.

In the Spring of 2021, approximately 400 students were enrolled in the course, spread across 14 lab sections facilitated by pairs of TAs. Students were also spread across 4 different lecture sections with different instructors teaching identical curricula. Of the students in the course, 178 of them consented to participate in the study.

Development and Implementation of the Modules

The development of the modules began in Fall 2020, based on some of the preliminary emerging themes from the interviews conducted at that time with engineering students [24]. Two design strategists met with the course instructor several times before the semester and throughout it to develop two modules. The topics for these modules were selected based on the unmet needs and desires of students who are interested in learning non-technical skills and working on more "real world" projects [24].

The first module gives students an overview of human-centered design and its processes. It focuses on introducing students to the idea of examining their personal assumptions and biases at the beginning of the design process. This practice is critical to the exploration process that takes place during a human-centered design approach to a design challenge as designers attempt to understand the context of the challenge and the different stakeholders [11]. The module consists of a pre-lab component, completed individually, where students are asked to document what they believe will be the most significant challenges of a hypothetical project prompt. Afterwards. students are introduced to a few perspectives they may have neglected when identifying those challenges. Students are then asked to reflect on what they wrote and what personal beliefs and experiences they have that led to the assumptions they wrote. For the in-lab portion of the module and to engage students in thinking collaboratively about their answers to the pre-lab component, students gather in their lab teams of 3-4 during synchronous virtual laboratory sessions to share their assumptions and answer a series of reflection questions.

The second module centers around the importance of storytelling and crafting a compelling narrative to engage your audience. This practice is associated with the communicative mindset of the human-centered design approach. Throughout the course, students are tasked with recording short demonstration videos of a few of the labs to demonstrate their understanding of the engineering concepts. The second module takes the form of a pre-lab assignment before the final presentation video. This pre-lab (also completed individually) guides students through a series of questions to help them think about how they might structure their presentations if they were presenting to incoming students to the course in an effort to inspire excitement about the course content.

Data Collection and Analysis

A pre and post-survey was designed and administered to measure the impact of the modules on students' learnings. One hundred and seventy-eight students took the pre and post surveys. The survey was composed of four sections. Items of Section A were three open-ended questions that asked students to report their definition of HCD, describe any past experiences they have with HCD processes or practices in engineering, and explain what they think the role of HCD is in engineering projects.

To rate students' responses to the three open-ended questions, we adapted two coding schemes from Shehab and his colleagues [25] and developed a third coding scheme based off work on the role of human-centered design in Engineering [20], [26]. The coding schemes are shown in Tables 1, 2, and 3 respectively.

Table 1. Coding scheme of students' definitions of HCD

Rating	Definition	Example
Naive	The definition is broad and does not indicate that HCD is a problem-solving approach or mention any of its characteristics.	*A design focused on improving human lives and efficiency.*
Intermediate	The definition includes that HCD is a	*Human-Centered Design is a*

	problem-solving approach and points out at least one of its major characteristics.	*problem-solving approach in which every step in the process takes into account the human perspective.*
Informed	The definition includes that HCD is a problem-solving approach and points out its three major characteristics: identification of the unmet need of a population, collaboration with the stakeholders, and iterating to develop meaningful solutions.	*Human-Centered design is a problem-solving approach used to identify problems and ideate solutions to that problem through a holistic process involving the considerations of the affected party, surrounding circumstances, the financial and resource barriers.*

Table 2. Coding scheme of students' description of the HCD processes

Rating	Definition	Example
Naive	The response only includes a broad and general description of HCD processes.	*Being aware of the audience and understanding others.*
Intermediate	The response includes a specific description of only one HCD process such as emphasizing with stakeholders.	*HCD includes asking about what the people might want or find important in the design and what might not be necessary and revisiting those perspectives when imagining and re-imagining a design.*
Informed	The response includes description of multiple and specific HCD processes associated with core HCD activities such as understand, synthesize, ideate, prototype, and implement.	*HCD includes gathering feedback from a wide audience for their thoughts and suggestions on a prototype before a finalized product. It also includes brainstorming ideas along with teammates to solve a given problem and narrow does the best approach to use and test.*

Table 3. Coding scheme of students' description of the role of HCD in engineering design

Rating	Definition	Example
Naive	The description is broad or only indicates that a human-centered design is a product of engineering design.	*HCD plays a role in product design used by people.*
Intermediate	The description indicates an integration	*Human-centered design is a*

	between HCD processes and engineering design but does not articulate how the engineering design processes influence HCD processes and vice versa.	*necessary element of any engineering project, because it promotes inclusivity, and allows for every user to have a similar experience using the product.*
Informed	The description indicates an integration between HCD processes and engineering design and clearly articulates how the engineering design processes influence HCD processes and vice versa.	*HCD in engineering includes working in a team to brainstorm ideas for the client, narrowing down the questions and go with more defined options, brainstorming solutions and building a prototype, gather feedback and suggestions for the prototype, then test and work on the final product. This approaches a problem, defines the options and solutions, and incorporates human input and feedback for their final product.*

To achieve interrater reliability, two researchers coded 20% of the students' responses to each of the three questions in the pre and in the post-survey. Percent agreements were all greater than 80%. Frequencies of the different ratings of students' responses to the three open-ended questions were calculated and compared to assess the impact of the modules on students' understanding of HCD and its role in engineering design.

Items of Sections B, C and D were 5-points Likert scale items adapted from validated and reliable surveys reported in [27], [28], and [29] respectively (see Appendix). To assess the reliability of each of the three sections, Cronbach's alpha was calculated using the responses to the pre and post-survey items. Section B had seven items with a Cronbach's alpha of .75 for the pre-survey and .81 for post-survey. Section C had five items with a Cronbach's alpha of .81 for the pre-survey and .78 for post-survey. Section D had four items with Cronbach's alpha of .90 for the pre-survey and .93 post-survey. The Cronbach's alpha values of all sections indicated significant internal consistency between items of each of the three sections. A paired sample t-test was used to assess the impact of the modules on students' knowledge of performing the HCD processes associated with completing the engineering design challenges in this course and their development of the collaborative and communicative mindsets.

Results

Students' Understanding of HCD and its Role in Engineering

Figure 1 shows the frequency of the naive, intermediate, and informed definitions of HCD that the students reported in the pre and post surveys. The figure indicates that after engaging in the modules, less students had a naïve understanding of HCD and more students had an intermediate understanding of HCD. The number of students who had an informed understanding of HCD was very similar before and after engaging in the modules.

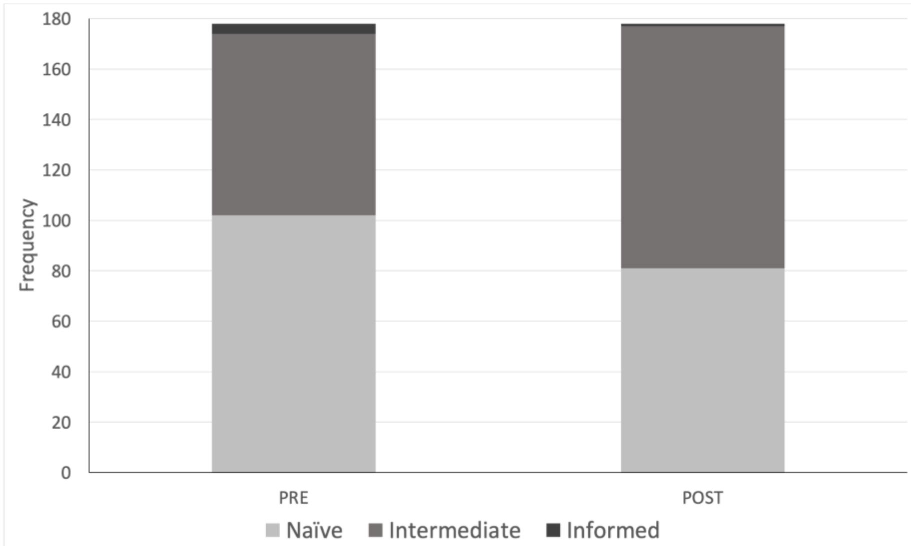

Figure 1. The Frequency of Naive, Intermediate, and Informed Definitions of HCD

Figure 2 shows the frequency of the naive, intermediate, and informed descriptions of the HCD processes that students reported in the pre and post surveys. The figure indicates that before engaging in the modules, 117 students did not respond the question. After engaging in the modules, this number decreased to 31 indicating an increase in the number of students who had naïve, intermediate, or informed understanding of the HCD processes. Moreover, after engaging in the modules, more students had an intermediate understanding of the HCD processes. However, after engaging in the modules, less students had an informed understanding of the HCD processes.

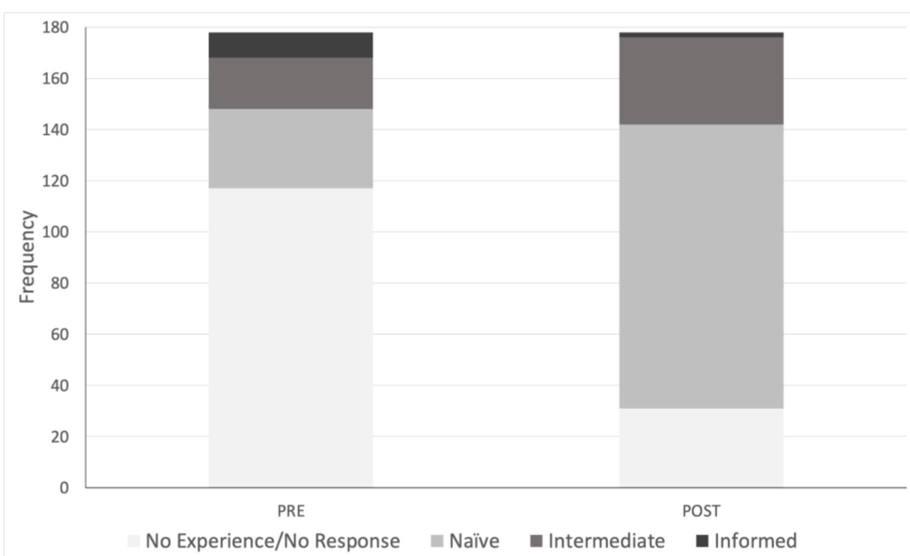

Figure 2. The Frequency of Naive, Intermediate, and Informed Descriptions of HCD Processes

Figure 3 shows the frequency of the naive, intermediate, and informed perceptions of the role of HCD in engineering projects. The figure indicates that after engaging in the modules, less students had a naïve understanding of the role of HCD in engineering; however, this number remained high. The figure also indicates that after engaging in the modules, few more students had an intermediate and informed understanding of the role of HCD in engineering.

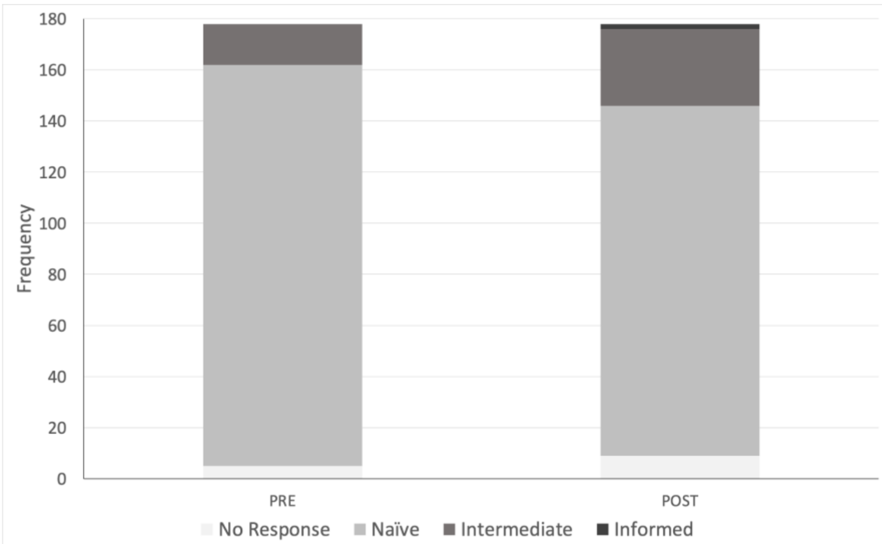

Figure 3. The Frequency of Naive, Intermediate, and Informed Understanding of the Role of Engineering in HCD.

Students' Knowledge of Performing the HCD Processes

To measure the impact of integrating the HCD modules on students' knowledge of performing the HCD processes that are associated with completing the engineering design challenges in this course, we conducted a paired sample t-test on Section B of the survey. The results of the test indicated a significant improvement in students' knowledge of performing the HCD processes that are associated with completing the engineering design challenges in this course after engaging in the modules (M=27.94, SD=3.63) compared to before engaging in the modules (M=26.07, SD=3.60); t(177) = -6.54, p = 0.00.

Students' Development of the Collaborative and Communicative Mindsets

To measure the impact of integrating the HCD modules on students' development of collaborative and communicative mindsets, we conducted a paired sample t-test on Sections C and D of the survey. The results of the test indicated a significant improvement in students' group work skills associated with the collaborative mindset after engaging in the modules (M=20.59, SD=2.58) compared to before engaging in the modules (M=20.06, SD=3.37); t(177) = -2.14, p = 0.03. However, the results of the test also indicated no significant improvement in students' presentation skills associated with the communicative mindset after engaging in the modules (M=11.30, SD=4.51) compared to before engaging in the modules (M=11.49, SD=4.06); t(177) = .46, p = 0.65.

Discussion and Conclusion

This Work-In-Progress study describes and evaluates the design and integration of HCD modules into an existing Introduction to Electronics course. Two modules that aimed to 1) engage students in learning about human-centered design and its role in engineering and 2) engage students in team-based discussions and storytelling activities were designed and integrated in two laboratory sessions of the course. A pre and post-survey was completed by 178 students in order to assess the impact of the modules on students' understanding of HCD and its role in engineering, and development of skills associated with the collaborative and communicative mindsets.

Findings from this study indicated that after engaging in the modules, more students had a better understanding of HCD and its processes. Moreover, there was a significant improvement in students' knowledge of performing the HCD processes that are associated with completing the engineering design challenges in this course. Supported by findings from other studies that intentionally engage engineering students in HCD activities [30]–[32], these findings suggest that such activities can enrich engineering students' understanding of HCD and its processes, especially when the activities include reflective exercises that engage students in thinking about their learnings [32]. These activities can also assist students in developing the knowledge to perform HCD processes that are relevant to solving engineering design challenges. These processes align with what expert engineers implement to effectively complete design challenges [33] and can better prepare students to succeed in future work endeavors.

Findings from this study also indicated that after engaging in the modules, many students still had a naïve understanding of the role of HCD in engineering. This suggests that students' perceptions of HCD and its role in engineering cannot be easily altered. A significant change in these perceptions require multiple experiences with HCD in different courses including immersive experiences that involve real clients and users [20]. Nevertheless, engaging students in HCD modules in this course may better prepare them for immersive experiences in other courses. Therefore, engineering instructors need to continue to find opportunities to integrate HCD modules in their courses. These modules can be easier to design and integrate in existing courses compared to immersive HCD experiences that include authentic projects.

Findings from this study also indicated that after engaging in the modules, a significant improvement in students' group work skills associated with the collaborative mindset but no significant improvement in students' presentation skills associated with the communicative mindset. By design, the first module intentionally required students to have team-based discussions and reflections around their assumptions and biases. Such activities are shown to positively impact collaboration [34] and thus, engaging students in these activities can explain the positive impact of the modules on the group work skills. The second module focused on the importance of storytelling and crafting a compelling narrative to engage the audience. It only included tasking students with recording short demonstration videos of a few of the labs to demonstrate their understanding of the engineering concepts by a series of questions to help them think about how they might structure their presentations if they were presenting to incoming students to the course. Nevertheless, the students did not have the opportunity to present their work to an audience and receive feedback. This may explain why the module did not impact students' presentation skills. Future iterations of the modules need to offer students this experience in order to examine its impact on students' presentation skills.

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Appendix

	Item #	Item
Section B	1	When working on a project, I know how to document my biases, assumptions, and predictions.
	2	When working on a project, I know how to reflect on my biases, assumptions, and predictions.
	3	I know how to come up with ideas of potential solutions to a problem.
	4	I know how to come up with alternative solutions.
	5	During a project, I know how to develop a plan of action that outlines next steps and possible challenges.
	6	I know how to create a prototype
	7	I know how to communicate a final design

	Item #	Item
Section C	1	When working in groups, I tend to provide emotional support to my group members.
	2	When working in groups, I tend to remind the group how important it is to stick to schedules.
	3	When working in groups, I tend to be sensitive to the feelings of people.
	4	When working in groups, I tend to show that I care about my group members.
	5	When working in groups, I tend to be open and supportive when communicating with others.

	Item #	Item
	1	I know how to effectively present a design orally

Section D	2	I can finish a technical report or oral presentation within an allotted time.
	3	I know how to present information in a logical and organized way.
	4	I know how to tailor technical reports and presentations to the target audience.