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Board 148: Ongoing Evaluation of Pre-College Students' Learning Outcomes During a Human-Centered Engineering Design Summer Camp

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I am currently the Associate Director of Assessment and Research team at the Siebel Center for Design (SCD) at the University of Illinois at Urbana-Champaign. I work with a group of wonderful and talented people at SCD's Assessment and Research Laboratory to conduct research that informs and evaluates our practice of teaching and learning human-centered design in formal and informal learning environments.

My Research focuses on studying students' collaborative problem solving processes and the role of the teacher in facilitating these processes in STEM classrooms.

WIP: Ongoing Evaluation of Pre-College Students' Learning Outcomes During a Human-Centered Engineering Design Summer Camp

Introduction

Engineering summer camps, which allow pre-college-aged students to participate in authentic design tasks, provide opportunity to experience topics or activities that may not be offered at school. Students have opportunities to preview college-level engineering education, explore potential college interests, and develop authentic collaboration skills.

In our ongoing study at the University of Illinois at Urbana-Champaign, we implemented a week-long human-centered engineering design camp in a design center that allowed students to immerse in a collaborative design task. Human-centered design (HCD) is a problem-solving approach that uses design thinking tools to identify unmet needs of a population in order to collaboratively and iteratively develop meaningful and innovative solutions [1]. To effectively prepare engineering students for navigating the demands and nuances of the workplace while being mindful of their users' needs, it is necessary to train them to consider the design problem through both technical and human-centered perspectives [2]. Previous work noted universities' increasing tendency to incorporate HCD in existing engineering programs and to use it as another means of supporting students' achievement of desirable learning outcomes [2]. Our efforts to contribute to this educational trend led to the development of an educational summer camp meant to expose high school students to a team-based human-centered design task.

Background

In this work-in-progress paper, we document the second iteration of our HCD-based camp. Given our preliminary results [3], we iterated the camp's design and performed a second round of data collection to better understand the impact of our activities on students' learning outcomes. During the first iteration, we noticed a positive impact on students' interest in pursuing an engineering career, their awareness of what engineers do in an engineering career, and their awareness of the role of HCD in engineering.

Our previous work [3] primarily addressed the implications of the introduction of HCD on engineering design pedagogies. In this paper, we examine the reciprocal influence of traditional engineering contexts on HCD. This paper seeks to answer the following research questions:

RQ 1: What is the impact of the camp on students' attitudes towards human- centered design?

RQ 2: What is the impact of the camp on students' awareness of the role of HCD in engineering?

RQ 3: What is the impact of the camp on students' improvement in group work skills?

Methods

Participants

The study consisted of aspiring college students in high school with an age range of 15-18. Two groups of high school students participated in two week-long sessions. The first group had 14 students (8 male, 6 female) and the second group had 17 students (10 male, 6 female, 1 non-binary). There are no repetition in participants from the previous iteration. Week one featured a five-day Monday to Friday schedule with a 9AM to 5PM day camp format. Week two featured a four-day Tuesday to Friday schedule with a residential camp format, during which students stayed on campus throughout the week.

Implementation of the Camp

The implementation of the camp revolved around four main learning objectives being: to use human-centered design as an approach to creative problem-solving, to practice employing design thinking tools to identify and understand user needs, to work collaboratively in interdisciplinary teams, and to create physical prototypes and provide constructive feedback. Over the course of the five-day camp, students immersed in an experiential design task that encompassed a combination of individual and small group activities, lectures, and scheduled breaks. The camp followed HCD taxonomy such that students progress through the Understand, Synthesize, Ideate, and Prototype taxonomic spaces sequentially [4]. Students were encouraged to return to previous spaces if needed. Roughly 80% of camp time was spent in facilitated activities and experiential learning and 20% in lectures.

In the Understand space, instructors presented an introduction to HCD through a set of mini-lectures on HCD taxonomy, identifying bias, identifying extreme users, and conducting meaningful interviews. Next, students were introduced to the design project and divided into mixed gender groups of 3-4. To explore the Understand space in the HCD taxonomy, each student group was given a user-defined need to accompany a children's space projector and were tasked to first dissect the projector, then build a modified version to fit the user-defined need. Dissection took place at a fabrication shop and students had access to tool kits. During the dissection activity, each group was asked to create a Bill of Materials (BOM) and correctly reassemble the projector. In addition, a reverse interview activity was organized. students and instructors took turns being interviewed for their assigned personas, and each group collected data accordingly. The user persona and the reverse interview activity served as the design problem formulation for each student group.

During the Synthesize space, groups were asked to consolidate their interview data. Each group participated in a reflection session to consider the challenges each user persona faced and narrow the problem down to a few key ideas.

In the Ideate space, students were introduced to mind mapping and group brainstorming techniques through lecture. They then participated in a set of ideation activities. The first activity focused on an unrelated design problem, with each group brainstorming design ideas to help a mobility-restricted person eat an ice cream cone. Groups bounced ideas among one another and ultimately shared their three best design ideas with the rest of the groups. Next, students were tasked to rapidly brainstorm as many ideas as possible in 10 minutes on each team's design problem. Students took the 5 best ideas and expanded on each idea in a mind map activity on a large whiteboard. In addition, students were introduced to the resources available in this camp. These included crafting materials, 3D printers, wood and acrylic laser cutters, 3D CAD software, laptops, large format printers, soldering stations, and tool kits. Students were encouraged to inquire with instructors and shopkeepers about the operation of each machine and whether assistance was required with the machines.

In the Prototyping space, instructors gave a prototyping lecture on how to develop low fidelity prototypes. Activities included time-restricted rapid prototyping of a mug which can hold multiple liquids and team presentations on how each prototype was going to be used by the stakeholder. Lecture continued with how to choose the most valuable prototype through testing and iteration. After the lecture, students were free to prototype their ideas using the fabrication shop. Students were in a studio-based learning environment where teams took on a more active role in their own learning process. Periodically, various activities allowed groups to test each other's prototypes and provide feedback to one another. Students were allowed to take breaks at their own discretion, consult with design scholars, and access to media rooms at their discretion. Once the most valuable prototype was created, each team presented their prototype to facilitators and professionals in design thinking. Each team received feedback on their final presentations.

It was a secondary objective to introduce students to college life and experiences. Many students attending the camp were aspiring college students interested in discussing college applications, what it is like to live away from home, and how engineering and design thinking majors are, among many others. Therefore, this iteration of the camp had graduate and undergraduate instructors from engineering and design fields in addition to professional design scholars to better connect with each student.

Data Collection

To survey each student's response to items pertaining to attitude of HCD and awareness of the role of HCD in engineering, data was collected through a pre- and post-test survey on a 5-point Likert scale, with 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree. Another 5-point Likert scale was used for group work skills, with 1 = Not at All, 2 = Rarely, 3 = Sometimes, 4 = Often, 5 = Always. The survey used was an adaptation of the survey used in the last iteration of the camp [blinded]. All items were uni-directional with increasing numbers corresponding to increasingly desired responses. The pre-test survey was given in the morning of the first day of instruction, and the post-test survey was given in the afternoon of the last day of instruction.

Data Analysis

The combined datasets from both weeks were analyzed to evaluate whether students demonstrated improvement in each construct with a sample size of $n = 28$. Within each data set, each construct's Cronbach's alpha was calculated to quantify the internal consistency of the set of survey question items in each construct. A Shapiro test was used to check the normality of each construct's distribution. If normally distributed, a paired sample T-test was used to find significance. If not normally distributed, a Wilcoxon-Signed Rank Test was used to find significance. The significance threshold used to determine if a construct was significant is if the null-rejection hypothesis probability is 90% or above. An acceptable Cronbach's alpha value was 0.65 and above.

Also, a changed score method was developed to see how many students had positively progressed, had no change, or negatively progressed for each construct. For a set of questions in a construct, if a student reported a positive difference between pre- and post-test survey, a 1 was given for that question. If a student reported no difference between the pre- and post-test survey, a 0 was given for that question. If a student reported a negative difference between the pre- and post-test survey, a -1 was given for that question. The tallies were added up and a positive sum corresponded to a positive progression, a sum of 0 corresponded to no progression, a negative sum corresponded to a negative progression. More formally:

s = student
c = construct
$Q(c, s)_{ij}$ = numerically scaled Likert response matrix for each student and construct
$n(c)$ = number of questions in a construct

For each student in a construct, a score is calculated through Eq. 1 as:

$$G(Q) = \sum_{i=1}^{n} sgn(Q_{i,post} - Q_{i,pre}) \tag{1}$$

where the signum function is defined in Eq. 2 as:

$$sgn(x) = \begin{cases} -1, & if\ x < 0, \\ 0, & if\ x = 0, \\ 1, & if\ x > 1. \end{cases} \tag{2}$$

The $G(x)$ score is evaluated through the function $F(x)$ to find the composite score of each student in a respective construct as shown in Eq. 3:

$$Composite\ Score = \begin{cases} \text{Positively Progressed}, & if\ G(Q) > 0, \\ \text{No Change}, & if\ G(Q) = 0, \\ \text{Negatively Progressed}, & if\ G(Q) < 1. \end{cases} \tag{3}$$

Each student's composite scores were tallied for a given construct and the overall impact of the camp on each construct is shown in Table 3.

Results

Table 2: Figures of Merit

Construct	α (pre, post)	p-value	$\Delta\bar{x}$
Attitude of HCD	0.760, 0.683	0.011	0.321
Awareness of the role of HCD in Engineering	0.657, 0.650	0.035	0.179
Group work skills	0.760, 0.835	0.174	0.100

Table 3: Composite Score Results

	Positively progressed	No change	Negatively progressed
Attitude toward HCD	14	11	3
Awareness of the role of HCD in Engineering	11	13	4
Improvement of group work skills	15	3	10

RQ 1: What is the impact of the camp on students' attitudes towards human-centered design?

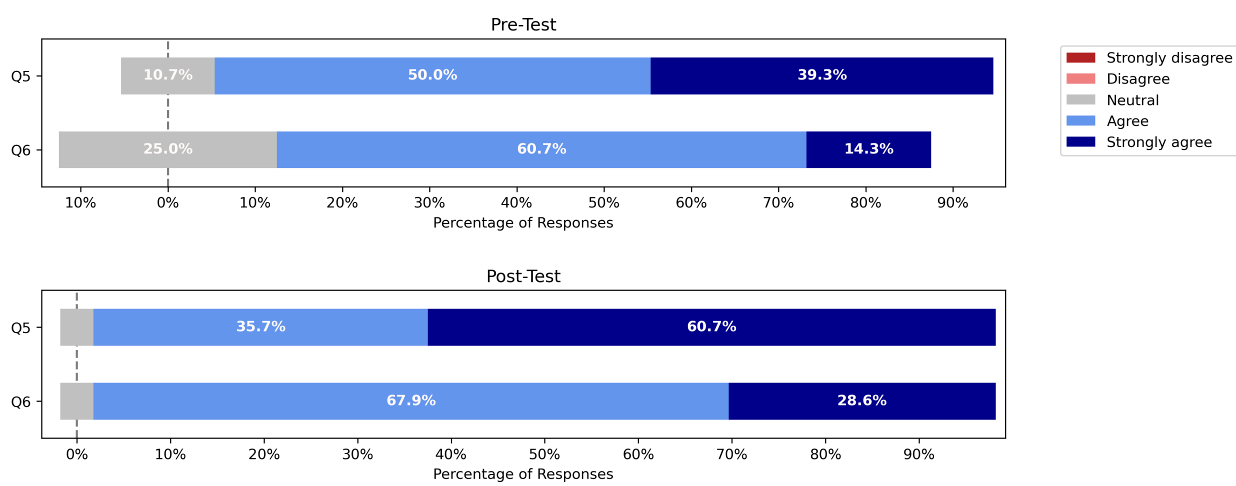

Figure 1: Survey Likert responses pertaining to the attitude toward human-centered design construct.

Table 2 shows the Wilcoxon signed-rank test indicated a 98.9% null hypothesis rejection; Cronbach's alpha values of $\alpha_{pre} = 0.76$, $\alpha_{post} = 0.68$; An aggregated change in average between pre- and post-tests of $\Delta\bar{x} = 0.321$. The composite scores show 14 had positively progressed, 11 had no change, 3 negatively progressed.

In Fig. 1, the pre- and post-test survey Likert distribution shows a clear positive shift in distribution. With the p-value and α within tolerance, this positive distribution shift is significant. This is further supported by the composite score data which suggests a heavy positive progression lean. Therefore, students experienced an significant improvement in attitude toward human-centered design.

RQ 2: What is the impact of the camp on students' awareness of the role of HCD in engineering?

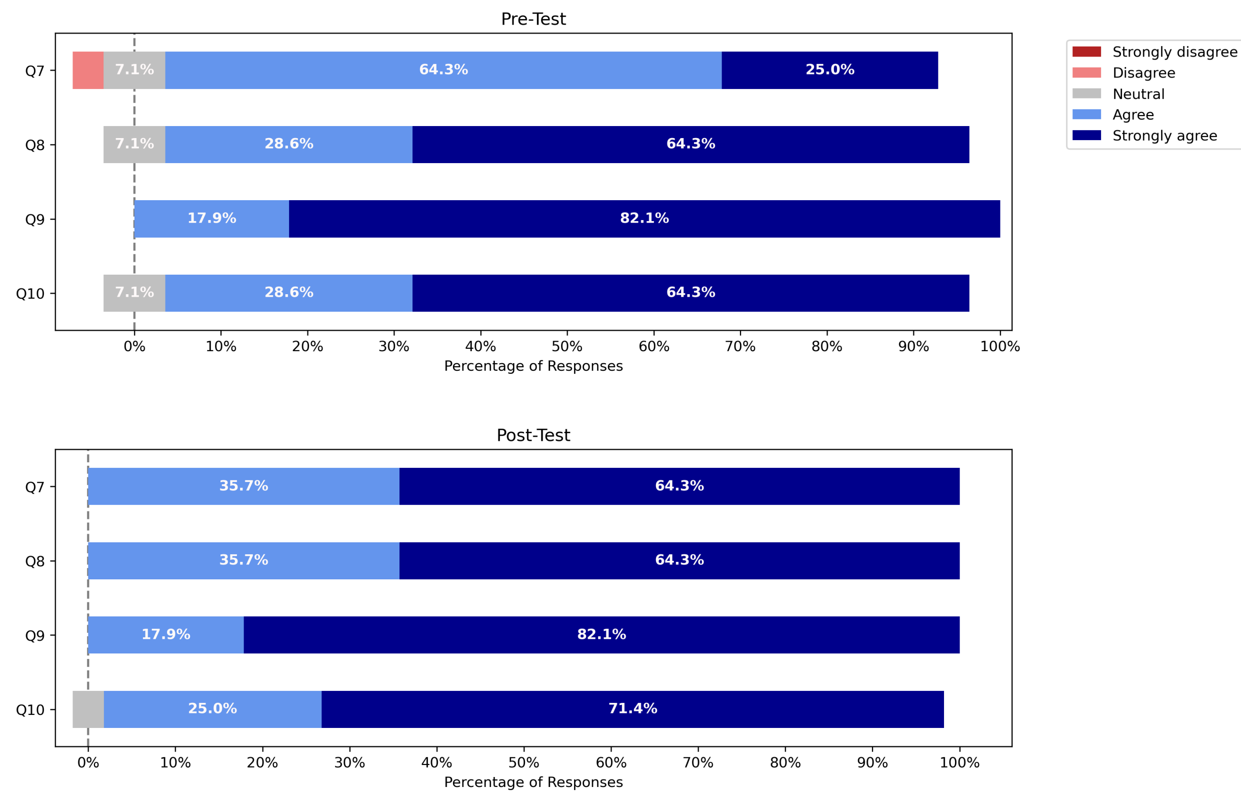

Figure 2: Survey Likert responses pertaining to the awareness of the role of human-centered design in engineering construct.

Table 2 shows the Wilcoxon signed-rank test indicated a 96.5% null hypothesis rejection; Cronbach alphas of $\alpha_{pre} = 0.66$, $\alpha_{post} = 0.65$; An aggregated change in average between pre- and post-tests of $\Delta\bar{x} = 0.179$. The composite scores show that 11 scores positively progressed, 13 had no change, and 4 negatively progressed.

In Fig. 2, the pre- and post-survey Likert distribution shifts are harder to discern, with a slightly positive shift. Looking at the composite score results, a clearer depiction of positive progression can be seen. With the p-value and α within tolerance, this positive progression is significant.

Therefore, students had an increase in awareness of human-centered design in engineering contexts.

RQ 3: What is the impact of the camp on students' improvement in group work skills?

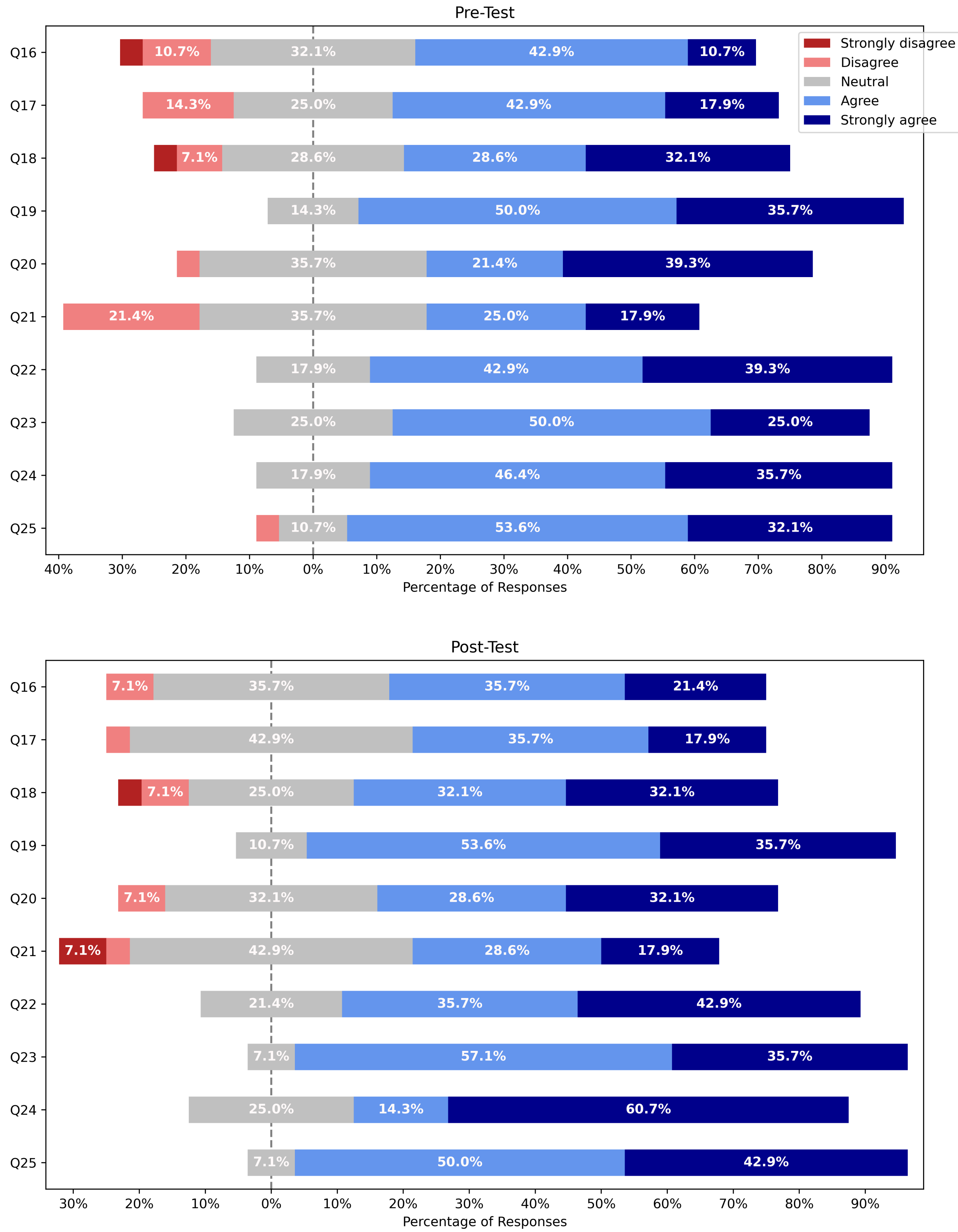

Figure 3: Survey Likert responses pertaining to the group work skills construct.

Table 2 shows the paired sample T-test indicated a 82.6% two-sided null hypothesis rejection; Cronbach's alphas of $\alpha_{pre} = 0.76$, $\alpha_{post} = 0.84$; An aggregated change in average between pre- and post-tests of $\Delta\bar{x} = 0.1$. The composite scores show that 15 positively progressed, 3 had no change, and 10 negatively progressed.

In Fig. 3, the pre- and post-test Likert distribution shifts are convoluted with some questions shifting negatively, other questions shifting positively, and some keeping the same distribution. Looking at the composite score analysis, a large percentage of the students ended up with either positively progressed or negatively progressed indicating a polarization. The extent of the polarization cannot be determined from the composite score. Furthermore, the α value is within tolerance but the p-value was outside of tolerance. Therefore, the camp had no significant impact on students' improvement of group work skills.

Discussion

Results indicate that students experienced an improvement in attitude toward human-centered design. This is promising for the implementation of HCD-based summer camps as a means of exposing pre-college-aged learners to design thinking methods in preparation for modern STEM education programs. It is possible that students tended toward a strong positive response during the pre-test because many thought "human-centered design" referred to the literal translation of design with humans rather than the human-centered design taxonomy and design processes. Interestingly, most students answered agree or strongly agree for the post-test, indicating that they agreed with human-centered design being an interesting and valuable practice.

Furthermore, results indicate that students experienced an increase in their awareness of human-centered design in engineering contexts. Establishing context for design thinking in engineering is important for engineering education because it lays the foundation for students to develop relevant mindsets necessary for discerning and implementing these methods in authentic design problems. Pre-college-aged students typically spend less time in the Ideate and Understand spaces [5], especially from the client's perspective, than experts [6]. Indeed, without scaffolding to direct student's collaborative problem solving, previous work has shown that they tend to skip problem framing or gathering information in lieu of attempting to solve [7]. Therefore, an increase in awareness of methods that encompass these processes shows the efficacy of the camp's design in exposing students to various facets of engineering problem solving.

In contrast, our results show no significant impact on the development of group work skills. Although we included group work skills as a metric of interest for the design of our camp, our focus was on students' immersion within the human-centered design process. Future work can more deliberately scaffold the development of students' group work skills, for example by engaging students in formative reflective exercises to self-evaluate their collaboration. Also, evaluation of group work skills in self-reported Likert data may not be the most meaningful way to measure the development of group work skills. Ethnographic data should be analyzed in conjunction with self-reported data to have a more thorough understanding of the potential for impact on students' development of these skills.

Conclusion

Our study is the second iteration of a human-centered engineering design camp with 28 participants from two, one week long summer camps. The summer camps utilized experiential learning techniques supplemented by lectures on core concepts in human-centered design and design thinking. Three Likert scale pre-/post-test survey constructs were constructed to assess the impact of the camp on learning progressions. These constructs encompassed attitudes towards human-centered design, awareness of the role of human-centered design in engineering, and improvement of group work skills. Our results show students experienced a significant improvement in attitudes towards human-centered design, a significant improvement in awareness of the role of human-centered design in engineering, but no significant improvement in group work skills. A composite score method was developed to better understand Likert data and agreed with the significance tests and trends seen in the data. Future work should encompass ethnographic data and observational protocols to further analyze each construct.

Appendix 1: Survey Items

Table 4: Pre/Post Test Items

Item Number	Item Content	Description of Scale	Construct
1	I think engineering is a rewarding career	strongly disagree disagree neutral agree strongly agree	
2	The advantages of studying engineering outweigh the disadvantages	strongly disagree disagree neutral agree strongly agree	
3	I can think of several other majors that would be more rewarding than engineering	strongly disagree disagree neutral agree strongly agree	
4	From what I know, engineering is interesting	strongly disagree disagree neutral agree strongly agree	
5	I think human-centered design is a valuable practice	strongly disagree disagree neutral agree strongly agree	A
6	From what I know, human-centered design is interesting	strongly disagree disagree neutral agree strongly agree	A
7	I think human-centered design and engineering are related	strongly disagree disagree neutral agree strongly agree	B
8	It is important for engineers to understand what users need from a product or service	strongly disagree disagree neutral agree strongly agree	B
9	It is important for engineers to understand how the design of a product may impact users	strongly disagree disagree neutral agree strongly agree	B
10	It is important for engineers to understand who the end-users are for a product	strongly disagree disagree neutral agree strongly agree	B
11	Engineers need to work in a team	strongly disagree disagree neutral agree strongly agree	
12	Engineers need to work with experts outside of their field	strongly disagree disagree neutral agree strongly agree	
13	I feel like I know what an engineer does	strongly disagree disagree neutral agree strongly agree	
14	Teamwork is important for human-centered design	strongly disagree disagree neutral agree strongly agree	
15	Teamwork is important for creating a customized solution for a user's need	strongly disagree disagree neutral agree strongly agree	
16	I provide emotional support to my group members	not at all rarely sometimes often always	C
17	I remind the group how important it is to stick to schedules	not at all rarely sometimes often always	C
18	I am sensitive to the feeling of other people	not at all rarely sometimes often always	C
19	I construct strategies from ideas that have been raised	not at all rarely sometimes often always	C
20	I show that I care about my group members	not at all rarely sometimes often always	C
21	I clearly define the roles of each group member	not at all rarely sometimes often always	C

22	I am open and supportive when communicating with others	not at all rarely sometimes often always	C
23	I move the group's ideas forward towards a strategy	not at all rarely sometimes often always	C
24	I am there for other group members when they need me	not at all rarely sometimes often always	C
25	I evaluate how l the group is progressing towards agreed goals	not at all rarely sometimes often always	C

Construct A: Attitude toward HCD
Construct B: Awareness of the role of HCD in engineering
Construct C: Group work skills

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