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Evaluating the Impact of a One-Week Human-Centered Design Engineering Summer Camp on Pre-College Students' Learning Outcomes (RTP)

Miss Taylor Tucker, University of Illinois Urbana-Champaign

Taylor Tucker earned her bachelor's in engineering mechanics and master's in curriculum & instruction from the University of Illinois Urbana-Champaign. Her research focuses on promoting teamwork in complex engineering problem solving through collaborative task design. As a Fellow at the Siebel Center for Design, she currently co-leads the integration of human-centered engineering design principles within select courses across the Grainger College of Engineering.

Dr. Saadeddine Shehab, University of Illinois at Urbana-Champaign

Saadeddine Shehab is currently the Associate Director of Assessment and Research at the Siebel Center for Design (SCD) at the University of Illinois at Urbana-Champaign. He works with a group of undergraduate and graduate SCD scholars at SCD's Assessment and Research Laboratory to conduct research that informs and evaluates the practice of teaching and learning human-centered design in formal and informal learning environments. His research focuses on studying students' collaborative problem-solving processes and the role of the teacher in facilitating these processes in STEM classrooms that feature the learning of STEM through design.

Evaluating the Impact of a One-Week Human-Centered Engineering Design Summer Camp on Pre-College Students' Learning Outcomes

Taylor Tucker, Siebel Center for Design, tdtucke2@illinois.edu
Dr. Saadeddine Shehab, Siebel Center for Design, shehab2@illinois.edu

Engineering summer camps provide pre-college aged students with the opportunity to experience topics or activities that may not be offered at school. These opportunities can help students to diversify their learning and explore personal interests. In this study, we developed and implemented a week-long camp that guided 30 high school students (15 females and 15 males) through a collaborative human-centered engineering design task to explore the relationship between engineering design and human-centered design. Human-centered design (HCD), is an important characteristic of the future direction of engineering education. Indeed, the Accreditation Board for Engineering and Technology, Inc. (ABET) includes teamwork and empathic thinking among its student outcomes. Literature has defined six human-centered design mindsets that include collaboration, a key component of problem solving. Our previous work has stressed the importance and impactfulness of fostering collaboration in engineering education; in the same vein, we structured our camp activities around the collaborative mindset. In this paper, we report results from pre/post surveys to understand the impact of our camp on students' awareness of what engineers do in engineering careers and their interest in engineering as a career as well as their awareness of the role of HCD in engineering. Findings indicated that students' awareness of what engineers do, their interest in engineering, and their awareness of the role of HCD in engineering all improved. This can lead students to make a more informed decision regarding engineering as a potential career path. Future work will more deeply explore the camp's outcomes, especially regarding students' development of the collaborative (i.e., teamwork) mindset.

Introduction

Within the realm of STEM-related topics, human-centered design (HCD) is relatively young in its own right. Aptly named, HCD is an empathic approach to solving complex problems that focuses on identifying the direct needs of the end-user or stakeholder and employing a collaborative and iterative design process to achieve a customized solution [1]. This is a different approach than the more traditional design methods typically taught in undergraduate engineering courses, which focus on process efficiency and product optimization [2]. Empathy is recognized as an important element of students' emotional engagement [3], both with their design task and their teammates. Furthermore, the development of empathy is necessary for promoting emotional intelligence [4], making HCD valuable for students' personal development. 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.

The Siebel Center for Design offers multiple undergraduate-level courses that expose students to elements of HCD and its iterative design process [5]. However, our team's scope goes beyond making HCD accessible to students already in college. It is equally important to consider ways in which the world of STEM can be made accessible to high school students who are navigating the post-high school planning process. As educators, it is our duty to expand students' horizons and help them discover different educational opportunities and potential career paths. One way that our team can fulfill this duty is by exposing high school students to the world of human-centered engineering design (HCED) and supporting them in exploring related interests. We designed a week-long summer camp that uses principles of human-centered design, engineering design, and teamwork to help students explore and experience an authentic human-centered engineering design project. The purpose of this paper is to evaluate the impact of the camp on students' awareness of what engineers do in engineering careers and their interest in pursuing an engineering career as well as their awareness of the role of HCD in engineering.

Background

STEM, which represents topics within, connections among, and products of the realms of science, technology, engineering, and math, is becoming increasingly prevalent in modern education. However, the scope of STEM as an educational focus is still developing. Indeed, a 2011 study of graduate students and administrators in a STEM education & leadership program found that the concept of "STEM" was not well understood—despite being trained in STEM, more than half the participants were unable to accurately explain the concept [6]. Thus, even though STEM has gained considerable ground in the past decade, it is necessary to continue exploring the concept in a variety of educational settings, and to make such an education accessible to more students. It is also important to support students' inherent interest in STEM, including during their pre-college careers. Radunzel et al.'s recent study [7, p. 1] found that "students with both expressed and measured interest in STEM were more likely to persist and complete a STEM degree than those with either expressed or measured interest only, as well as those with no interest in STEM." Furthermore, research is investigating the troubling phenomena of extended time to finish college and higher drop-out rates for STEM programs as compared to others [e.g., 8].

STEM by the numbers

Pines [9] writes that "one of the greatest and most enduring strengths of the United States has been its ability to attract global talent in science, technology, engineering, and mathematics (STEM) to bolster its economic and technological competitiveness." However, he also reports that “while the US Bureau of Labor Statistics predicts STEM jobs will grow twice as fast as other occupations by 2029, research continues to show high school students have declining interest in STEM fields” [9]. According to the National Science Foundation (NSF)’s National Science Board (NSB)’s “The State of U.S. Science and Engineering 2022” report, the USA leads on the world stage for research and development [10] and also awards the most science and engineering doctorates of any nation. Furthermore, STEM careers represent 23% of the total US labor force. However, the NSB reports that “disparities in K-12 STEM education and student performance across demographic and socioeconomic categories and geographic regions are challenges to the US STEM education system” [10]. External education resources (like summer camps) have the potential to assist educators in addressing these challenges.

Within the realm of STEM, technology and engineering education are significantly less accessible than that of math or science. A 2021 census report tabulated 23,882 public high schools, plus 2,845 private schools, in the US, with 16.9 million students enrolled (1,539,000 private) for the 2020-2021 school year [11]. Of the total student population, 89% (15,041,000) completed Algebra II or higher in math. 79% (13,351,000) took at least one general science course. However, only 15% (2,535,000) earned any engineering or technology credits [11]. Thus, there is still a great discrepancy among students’ exposure to the four different realms of STEM during secondary education. In turn, STEM degrees are not as prevalent in post-secondary education as those from more established, traditional fields of study. The National Center for Education Statistics (NCES) reports that of the 2 million bachelor’s degrees conferred during the 2018-2019 period for US colleges, 6% (126,700) were in engineering, following behind business (19%), health-related programs (12%), and social sciences and history (8%) [12]. Similarly, more than 66% of the 1 million associate’s degrees awarded during the same period focused on one of three major areas of study: liberal arts and sciences, health professions, and business [13]. There is a clear need to continue exposing students to STEM education, and to do so on a broader scale. One way that centers like ours can contribute to this movement is through summer camps, which can leverage existing cultural constructs to provide relatively low-cost educational opportunities nation-wide.

Our university’s college of engineering offers a plethora of STEM-related summer camps through its summer camp program, Worldwide Youth in Science and Engineering (WYSE) [14]. Our organization already collaborates with many of these summer camps to design and facilitate campers’ explorations in STEM topics. However, there is not yet a summer camp that provides an authentic, collaborative HCD-focused experience. Our new camp, People Designing for People: Exploring Relationships Between Human-Centered Design and Engineering, focused specifically on helping students develop teamwork and empathic design skills through participation in a collaborative, week-long project.

Importance of collaboration for students' development and learning outcomes

It is already understood that collaboration is an important element for strong learning outcomes in STEM education. Indeed, collaborative problem solving is prominently featured in face-to-face constructivist STEM classrooms [15]. Research also continues to show the positive impact of collaborative problem solving on STEM students' engagement in STEM fields and their readiness to successfully participate in the workplace [16], [17]. Collaboration is especially important for engineers, who typically work not only with their colleagues but also peers from other disciplines and experts in other fields [18]. We have been working to promote collaborative problem solving in engineering at the college level in a number of ways, including by implementing scaffolded, collaborative design tasks [19], [20]. We know from these studies that students experience and learn about collaborative problem solving by working on authentic, ill-structured engineering tasks. Our findings showed that students achieve stronger learning outcomes when they successfully engage in four necessary collaborative problem-solving processes: explore the problem, plan how to solve, attempt to solve and justify solutions, and evaluate solutions and consider alternatives [19]. Furthermore, scaffolding students' participation in these four processes impacted their engagement with the task at the cognitive level, which helped us to understand why our task design was effective [20]. In our scaffolding study, we hypothesized that each of the four problem-solving processes can be considered individual realms that require specific cognitive engagement for effective participation. Thus, students' engagement with the task and with one another would be motivated according to the realm in which they were collaborating.

Implementing human-centered design in a collaborative engineering design challenge

Human-centered design (HCD) is a problem-solving approach that uses design thinking processes and tools to identify the unmet needs of a population in order to collaboratively and iteratively develop solutions [1]. It provides individuals with a flexible structure for navigating ill-structured challenges [21] and generating creative and meaningful solutions [22]. When using HCD, individuals focus on humans in the design journey by emphasizing with and understanding stakeholders, collaborating with them to explore and define problems [23], [24]. They also engage the stakeholders in iterative cycles of prototyping, testing, and reflecting to develop and sustain solutions [1]. HCD practices include documenting biases and assumptions, interviewing, identifying themes, communicating ideas, creating low-fidelity prototypes, and developing plans to bring final designs to the market [25], [26]. Figure 1 is a model that outlines the five major spaces and processes of HCD [27].

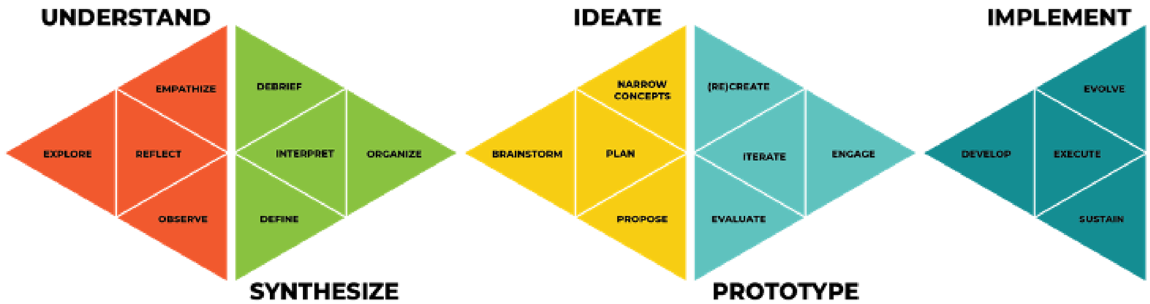

Figure 1: The Human-Centered Design Spaces and Processes

The idea of engineering design as a prescribed, linear process does not necessarily capture its true nature. Indeed, human-centered design recharacterizes the design process as iterative and empathic [28], [29]. It follows that human-centered design embodies a crucial component of a well-rounded engineering education, which should support the development of students' design skills [30]. Engaging students in human-centered design can also help them develop human-centered, metacognitive, collaborative, experimental, creative, and communicative mindsets [31], [32]. Thus, it is important to support human-centered design as a core component of engineering curricula. Doing so can better prepare students for a diverse, collaborative workplace in industry as well as help them to balance their technical and subjective design decisions.

Researchers argue that students can benefit from learning about and implementing HCD processes to become lifelong learners and problem solvers [33], [32]. Research studies continue to show that engaging students in activities to learn about and implement the HCD processes in the context of a collaborative design challenge positively influences their knowledge of performing these processes and their development of mindsets such as collaboration and communication [34]. Other studies have also shown that engaging students in activities to learn about and implement the human-centered engineering design (HCED) process in the context of a collaborative design challenge positively influenced students' understanding of the role of HCD in engineering [35] and interest in engineering [36]. In light of the positive impact on students' learning, we structured the camp's collaborative engineering design challenge around the HCD process presented in Figure 1. We believe that engaging students in learning about and implementing HCED can increase their engagement in the four collaborative learning processes in a more structured and authentic fashion. The camp's challenge constituted a set of hands-on activities that engaged groups in learning about and implementing two major HCED activities: understanding the challenge and iterating on a concept.

Significance of hands-on learning

Research has shown that hands-on learning, or learning by doing, is more effective than simply listening to the lecture [37]. Hands-on learning is a cohesive pedagogy for collaborative work because it inherently supports productive failure [38]. When students are moved to struggle together, they enter the zone of proximal development. This is defined as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers" [39 p. 86]. Learners are considered to be in their zone of proximal development when they can accomplish a task or master a skill set with assistance [40]. In the context of undergraduate education, this can be done in collaboration with peers. Thus, engaging students in collaborative, hands-on learning can support their mastery of task content and related skills.

Overview of the summer camp

Our design task included a hands-on learning element in the form of product dissection. The dissection process, in which students work on reverse-engineering a product through physical deconstruction, provides experiential opportunity for practicing design [41], [42]. Also known as "disassemble, analysis, assemble," dissection has become a common pedagogy for providing students with practical experience in the classroom [e.g., 43]. Indeed, research has found that reverse engineering is a valuable and common design method in the workplace [44], making dissection tasks a fitting pedagogy for authentic work for students. Previous work explored the impact of dissection on students' learning outcomes in a collaborative, open-ended design task [45]. Initial findings indicated that students' learning outcomes were directly impacted by their participation (or lack thereof) in small group-level dissection of an object during their design task.

We want to expose students at the high-school level to such types of collaborative problem solving so these learners have the opportunity to begin exploring career paths in engineering and develop awareness and interests in engineering careers. We did this by focusing on two key HCED activities: understanding the challenge and iterating on a concept. We addressed understanding the challenge through workshops that exposed students to identifying user needs, conducting user interviews, and synthesizing findings into an actionable solution. We addressed iteration through the combined design process of reverse engineering and prototyping. Prototyping is a valuable skill for novice designers, who tend to rely on their prototypes to communicate design outcomes and their effectiveness to an audience [46], [47]. As it is necessary to scaffold groups' transitions among steps, just as in previous work where we needed scaffolds to support students in entering each problem-solving process [19], our camp's structure relied on effective task design and strong instructor facilitation. Our study focuses on the following research questions:

RQ 1: What is the impact of the camp on students' interest in pursuing an engineering career and their awareness of what engineers do in an engineering career?
RQ 2: What is the impact of the camp on students' awareness of the role of HCD in engineering?

Methods

Study design

Design-based implementation research is a research approach that "applies design-based perspectives and methods to address and study problems of implementation" [48 p. 137]. In this study, we implemented a human-centered engineering design task that was designed according to methods identified in previous work [49], which included providing an introduction to the problem that provides context, a description of the problem itself, and supplementary material that provided information useful for solving the problem as well as outlining the specific tasks that campers were expected to achieve as a team and guidelines for their conduct as a team.

Participants

Participants were 30 students (15 females, 15 males) enrolled in high school. Students were enrolled in grades 9–12 for the following fall semester. The breakdown of participants per week is as follows: 18 students (10 females, 8 males) in week 1; 12 students (5 females, 7 males) in week 2. Week 1 was a residential session in which students resided on the campus for the duration of the week; week 2 was a day camp session in which students attended the camp between 9 AM and 5 PM. Participants were arranged in groups of 3–4 and had five days to complete the task.

Development of camp design project

We drafted four camp learning goals based on criteria identified in literature [e.g., 50]. These goals guided the development of the camp structure and task:

1. Campers will use human-centered design as an approach to creative problem solving.
2. Campers will practice employing design thinking tools to identify and understand user needs.
3. Campers will work collaboratively in interdisciplinary teams.
4. Campers will create physical prototypes and provide constructive feedback.

From our discussions and brainstorming, we concluded that reverse-engineering would be the most conducive to our learning goals given our constraints. This type of task includes the following: dissecting a commercial product to learn about its design, as well as documenting the process for future reference; identifying ways in which the product could be augmented, redesigned, or altered to address the existing need of a specific user group; and prototyping a solution to fit this need.

We then designed the task around a child's bedside projector toy, which contained sub-assemblies conducive to the dissection process. To guide campers in identifying user needs, we developed six possible personas. These were: a high school student, teacher, parent with small children, elderly person, doctor, and camper. To understand how to identify user needs through interviews, we included an exercise in drafting interview questions that includes facilitator feedback. Groups then received a persona in a blind selection. During the development and prototyping phases, groups had the opportunity to give and receive peer feedback through a guided session that took place during Day 4. Additionally, groups received facilitator feedback following their final presentations, delivered on Day 5.

Data collection and analysis

We used a pre/post survey (see Appendix) on a 5-point Likert scale, with 1 = Strongly disagree, 2 = Disagree, 3 = Neutral; 4 = Agree, and 5 = Strongly Agree, to elicit participants' opinions/feelings about engineering, HCD, teamwork, and relationships among these. The surveys, which were provided as a paper document, were adapted from the University of Pittsburg's Freshman Engineering Attitudes Survey [51]. All items (see Appendix) were written to align positive values with a desired agreement response. The pre-survey was given during the morning of Day 1, prior to the first classroom session. The post-survey was given following the design presentations during the afternoon of Day 5. Means were calculated for the pre- and post-survey responses and compared using descriptive statistics.

Results

Figures 1 and 2 provide the mean values for pre- and post-survey responses per each week.

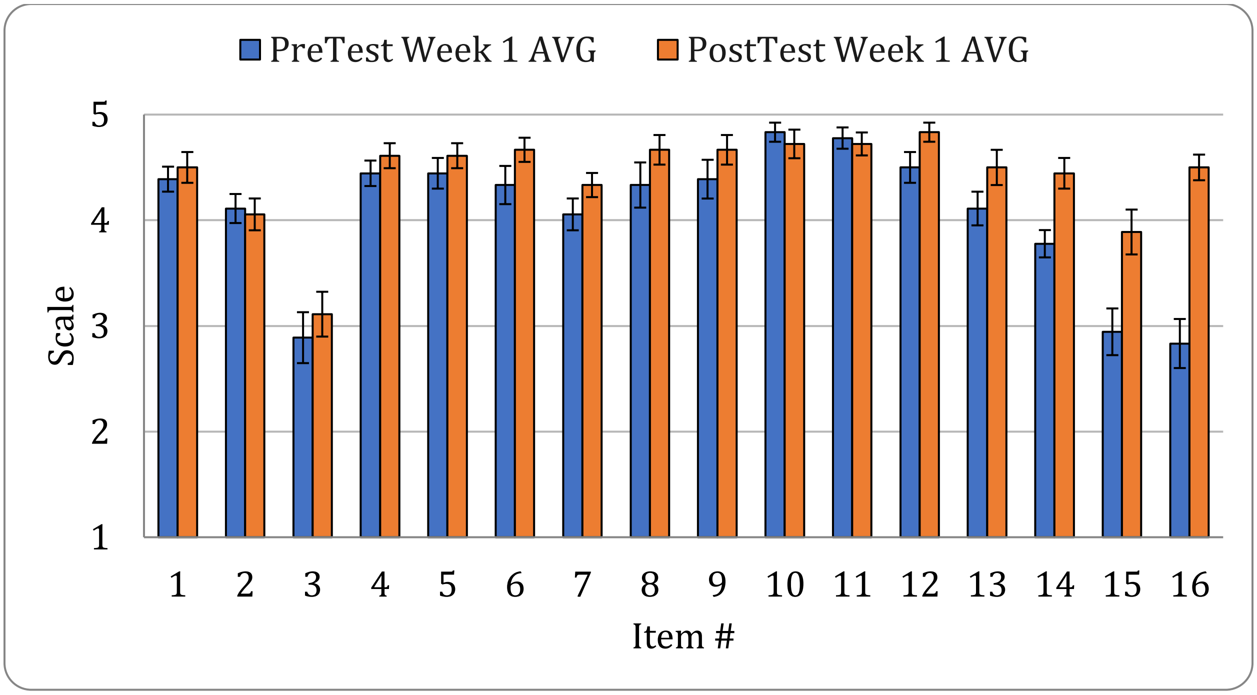

Figure 1: Average Survey Responses for Week 1

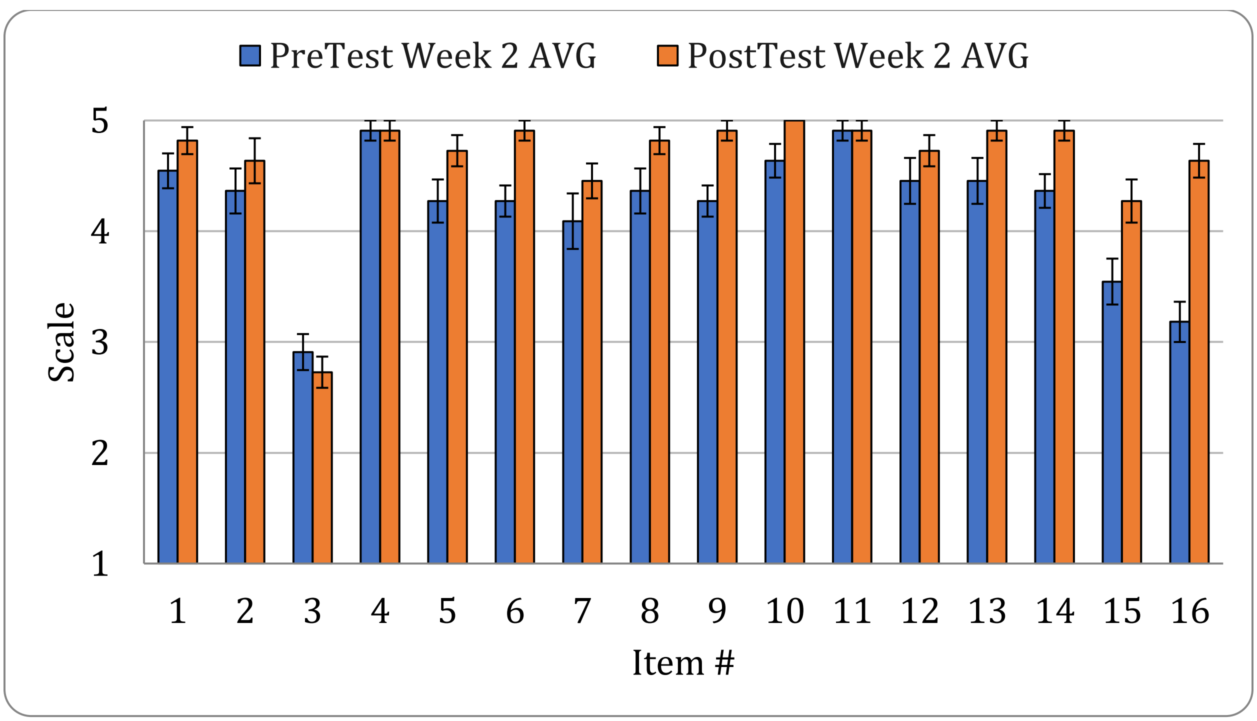

Figure 2: Average Survey Responses for Week 2

Figures 1 and 2 show that in both weeks, the mean values of the majority of students' responses on the post-survey items were higher than those on the pre-survey.

RQ 1: What is the impact of the camp on students' interest in pursuing an engineering career and their awareness of what engineers do in an engineering career?

Results for both weeks indicated that students' awareness of what an engineer does improved (items 8, 9, 15). Students' interest in pursuing an engineering career was also impacted (items 1, 2, 3, 4). In week 1, students' interest in engineering careers increased ("From what I know, engineering is interesting," item 4), but their opinion of engineering as a potential college major became less positive overall, with a slight decrease in item 2 ("The advantages of studying engineering outweigh the disadvantages") and an increase in item 3 ("I can think of several other majors that would be more rewarding than engineering"). In week 2, students' interest in engineering careers remained the same (item 4), but their opinion of engineering as a potential college major became more positive overall, with an increase in item 2 and a decrease in item 3.

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

Results for both weeks indicated that students' awareness of the role of HCD in engineering was impacted (items 6, 10, 11, 12). Both weeks saw an increase in items 6 ("I think HCD and engineering are related") and 12 ("It is important for engineers to understand who the end-users are for a product"). Interestingly, for both weeks, students' post-test responses placed slightly less importance on engineers' understanding of a design's impact on users (item 11). For week 1, students' post-test responses also placed less importance on engineers' understanding of user need (item 10); for week 2, post-test responses placed more importance on this understanding.

Furthermore, results for both weeks indicated that students' awareness of HCD improved (items 13, 14, 16) and that their interest in HCD also increased (items 5, 7).

Discussion

Our results indicated that our camp positively impacted students' awareness of what an engineer does in an engineering career and the role of HCD in engineering as well as their interest in pursuing an engineering career. This is an important step toward supporting students' interest in engineering careers. However, there were interesting differences between the groups of week 1 as compared to those in week 2.

It seems that students' experience during week 1 may have better informed them about engineering for better or worse. Although their awareness of the value in engineering as a career and their interest in the field of engineering both increased, their opinion of studying engineering as a major became less positive. Our organization's camper exit survey for residential camps (week 1) also reflected that the majority of students reported an improved understanding of engineering and an increased interest in engineering. Interestingly, the students still displayed intention to study engineering despite any changes in opinion, as 13 students reported that they are planning to study an engineering major in college. This may be in part because many of these students seem to have attended the camp with prior intention to apply to the hosting university for post-secondary education—15 students reported their intention to apply. Thus, the camp may have served as an introduction to both engineering and the college environment for students. Furthermore, 16 students reported that the camp met or exceeded their expectations for gaining understanding of engineering, and 17 reported that the camp met or exceeded their expectations for the resources it used. Thus, it seems that the camp was successful in immersing students in engineering, which raised their awareness of both the pros and cons associated with its study.

In comparison, students in week 2 left the camp with an increasingly favorable outlook regarding engineering as a potential college major. Because these students attended the day camp, they did not experience the college campus to the same extent as students in week 1. It is possible that their enjoyment of the camp led them to view studying engineering more favorably, without considering other factors associated with its study. Future work will investigate ethnographic observations of the students working together during camp to better understand their experiences.

Our results also indicated that our camp's design successfully raised students' awareness of the role of human-centered design in engineering. Surveys indicated that students' awareness of, and interest in, human-centered design both increased as a result of their immersion in the process. In light of these trends, it follows that their awareness of the role of HCD in engineering would also increase. Indeed, students in both weeks agreed that HCD and engineering are related (item 6). Their responses also indicated improved awareness regarding HCD tasks such as understanding the importance of teamwork for creating a customized solution to a user's needs (item 14). Additionally, they placed more importance on engineers' understanding of who end-users are (item 12). These findings are encouraging for the efficacy of the camp's design, as research has shown that high school students who have the opportunity to engage in design thinking typically do so without considering the client's perspective or needs [52].

However, it is important to note that students in both weeks also placed slightly less importance on engineers' understanding of a design's impact on users (item 11). Additionally, the two weeks were not in agreement regarding the importance of engineers' understanding of user need (item 10), with week 1 placing less importance in the post-test and week 2 placing more. It is possible that because students' awareness of the role of HCD in engineering improved, they were able to make more critical judgments regarding the importance of these items, which may have included questioning their importance. Follow-up work is needed to better understand students' thought processes with regard to engineers' understanding of user need.

Conclusion

In this study, we developed and implemented a week-long camp that guided 30 high school students through a collaborative human-centered engineering design task while exploring the relationship between engineering design and human-centered design. The goals of the camp were for campers to 1) use human-centered design as an approach to creative problem solving, 2) practice employing design thinking tools to identify and understand user needs, 3) work collaboratively in interdisciplinary teams, and 4) create physical prototypes and provide constructive feedback. We found that our camp's design successfully raised students' awareness of what engineers do in engineering careers and the role of human-centered design in engineering as well as increased their interest in pursuing an engineering career. Future work will more deeply investigate campers' experiences using observation data and other survey items. This work helps us to understand how the implementation of human-centered engineering design can be used to support students' learning outcomes during collaborative engineering tasks in particular and the evolution of collaborative task design in education in general.

Acknowledgements

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Appendix

Table 1: Survey items with change in average response from pre- to post-test by week.

#	Item
1	I think engineering is a rewarding career.
2	The advantages of studying engineering outweigh the disadvantages.
3	I can think of several other majors that would be more rewarding than engineering.
4	From what I know, engineering is interesting.
5	I think human-centered design is a valuable practice.
6	I think human-centered design and engineering are related.
7	From what I know, human-centered design is interesting.
8	Engineers need to work in a team.
9	Engineers need to work with experts outside of their field.
10	It is important for engineers to understand what users need from a product or service.
11	It is important for engineers to understand how the design of a product may impact users.
12	It is important for engineers to understand who the end-users are for a product.
13	Teamwork is important for human-centered design.
14	Teamwork is important for creating a customized solution for a user's needs.
15	I feel like I know what an engineer does.
16	I feel like I understand what human-centered design is.

References

[1] T. Brown, "Design thinking," *Harvard Business Review*, pp. 1–9, 2008.

[2]. The Accreditation Board for Engineering and Technology, "Accreditation," *The Accreditation Board for Engineering and Technology*, 2002. [Online]. Available: https://www.abet.org/accreditation/. [Accessed: Jan. 10, 2023].

[3]. Tucker, T., Vernooij, E., Wolf, A.R., Bo-Linn, C., Baird, R.T., Dancholvichit, N., & Liebenberg, L. (2020). Transforming an engineering design course into an engaging learning experience using e-Portfolios. ASEE's Virtual Conference: At Home with Engineering Education. American Society for Engineering Education. doi: 10.18260/1-2--35401. [4]. K. Cherry, "5 key emotional intelligence skills," *verywellmind.com*, Jan 26, 2022. [Online]. Available: https://www.verywellmind.com/components-of-emotional-intelligence-2795438. [Accessed Dec. 15, 2022].

[5] Siebel Center for Design [Building website]. https://designcenter.illinois.edu/. [Accessed Oct. 1, 2022].

[6] T. Brown and B. Katz, "Change by design," Journal of Product Innovation Management, vol. 28, no. 3, pp. 381–383, 2011. doi: 10.1111/j.1540-5885.2011.00806.x.

[7] J. Radunzel, K. Mattern, and P. Westrick, "The role of academic preparation and interest on STEM success," ACT Research Report Series, vol. 8, pp. 1–56, 2016.

[8] J. M. Hamm, R. P. Perry, and S. Hladkyj, "How STEM students explain their academic setbacks affects their graduation rates," *spsp.org*, Oct. 7, 2020. [Online]. Available: https://spsp.org/news-center/character-context-blog/how-stem-students-explain-their-academic-setbacks-affects-their. [Accessed Jan. 13, 2023].

[9] D.J. Pines, "Democratizing engineering for every high school student," *Issues in Science and Technology*, March, 2022. [Online serial]. Available: https://issues.org/democratizing-engineering-high-school-students-pines/. [Accessed Aug. 1, 2022].

[10] National Science Board, "The State of U.S. Science and Engineering 2022," *Science and Engineering Indicators (NSF)*, 2022. [Online]. Available: https://ncses.nsf.gov/pubs/nsb20221/executive-summary. [Accessed July 22, 2022].

[11] Think Impact, "High School Statistics," *Think Impact*, 2022. [Online]. Available: https://www.thinkimpact.com/high-school-statistics/. [Accessed July 22, 2022].

[12] Institute of Education Sciences, "Most popular majors," *National Center for Education Statistics*, 2022. [Online]. Available:https://nces.ed.gov/fastfacts/display.asp?id=37. [Accessed July 22, 2022].

[13] Institute of Education Sciences, "Undergraduate degree fields," *National Center for Education Statistics*, 2022. [Online]. Available: https://nces.ed.gov/programs/coe/indicator/cta. [Accessed July 22, 2022].

[14] The Grainger College of Engineering (2022). WYSE summer camps. Worldwide Youth in Science and Engineering Program. https://wyse.engineering.illinois.edu/summer-camps/

[15] C.E. Hmelo-Silver and C. A. Chinn, "Collaborative learning," in *Handbook of Educational Psychology*. Routledge, 2016.

[16] B. Barron and L. Darling-Hammond, “Teaching for meaningful learning: A review of research on inquiry-based and cooperative learning,” George Lucas Educational Foundation, 2008.
[17] S. Freeman, S. L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt, and M. P. Wenderoth, “Active learning increases student performance in science, engineering, and mathematics,” Proceedings of the National Academy of Sciences, vol. 111, no. 23, pp. 8410–8415, 2014
[18] D. Jonassen, J. Strobel, and C. Lee, “Everyday problem solving in engineering: Lessons for engineering educators,” Journal of Engineering Education, vol. 95, no. 2, pp. 139–151, 2006.
[19] T. Tucker, T., S. Shehab, and E. Mercier, “The impact of scaffolding prompts on the collaborative problem solving of ill-structured tasks by undergraduate engineering student groups,” in 127th ASEE Annual Conference. [Technical Session]. Montreal: American Society for Engineering Education, 2020.
[20] T. Tucker, S. Shehab, and E. Mercier, “The impact of scaffolding prompts on students’ cognitive interactions during collaborative problem solving of ill-structured engineering tasks,” in 128th ASEE Annual Conference. [Technical Session]. Virtual: American Society for Engineering Education, 2021.
[21] R. Buchanan, “Wicked problems in design thinking,” Design Issues, vol. 8, no. 2, pp. 5–21, 1992.
[22] M. Meinel, T. T. Eismann, C. V. Baccarella, S. K. Fixson, and K. I. Voigt, “Does applying design thinking result in better new product concepts than a traditional innovation approach? An experimental comparison study,” European Management Journal, 2022, doi: 10.1016/j.emj.2020.02.002.
[23] K. Dorst, “The core of ‘design thinking’ and its application,” Design Studies, vol. 32, no. 6, pp. 521–532, 2011, doi: 10.1016/j.destud.2011.07.006.
[24] T. Zhang and H. Dong, “Human-centered design: an emergent conceptual model,” pp. 1–7, 2008.
[25] U. Johansson-Sköldberg, J. Woodilla, and M. Çetinkaya, “Design thinking: Past, present and possible futures,” Creativity and Innovation Management, vol. 22, no. 2, pp. 121–146, 2013, doi: 10.1111/caim.12023.
[26] S. Panke, “Design thinking in education: Perspectives, opportunities and challenges,” Open Education Studies, vol. 1, no. 1, pp. 281–306, 2019, doi: 10.1515/edu-2019-0022.
[27] L. Lawrence, S. Shehab, M. Tissenbaum, R. Tingting, and H. Tyler, “Human-centered design taxonomy: Case study application with novice, multidisciplinary designers,” *AERA Virtual Annual Meeting.* Virtual: American Educational Research Association, 2021.
[28] C. Wrigley and K. Straker, “Design thinking pedagogy: The educational design ladder,” Innovations in Education and Teaching International, vol. 54, no. 4, pp. 374–385, Jul. 2017, doi: 10.1080/14703297.2015.1108214.
[29] S. Shehab and C. D. Schmitz, “WIP: The impact of human-centered design modules on students’ learning in an introduction to electronics course,” *129th ASEE Annual Conference.* Minneapolis: American Society for Engineering Education, 2022.
[30] C. J. Atman, R. S. Adams, M. E. Cardella, J. Turns, S. Mosborg, and J. Saleem, “Engineering design processes: A comparison of students and expert practitioners,” Journal of Engineering Education, pp. 359–379, 2007.

[31] S. Goldman, M. P. Carroll, Z. Kabayadondo, L. B. Cavagnaro, A. W. Royalty, B. Roth, S. H. Kwek, and J. Kim, "Assessing learning: Capturing the journey of becoming a design thinker," in Design Thinking Research, H. Plattner, C. Meinel, and L. Leifer, Eds. Berlin Heidelberg: Springer, 2012, pp. 13–33, doi: 10.1007/978-3-642-31991-4_2.
[32] R. Razzouk and V. Shute, "What is design thinking and why is it important?" Review of Educational Research, vol. 8, no. 3, pp. 330–348, 2012, doi: 10.3102/0034654312457429.
[33] J. H. L. Koh, C. S. Chai, B. Wong, and H. Y. Hong, *Design Thinking for Education.* Springer Singapore, 2015, doi: 10.1007/978-981-287-444-3.
[34] S. Shehab and C. Guo, "Measuring the impact of integrating human-centered design in existing higher education courses," in 2021 Learn x Design 6th International Conference for Design Education Researchers.
[35] A. Pagano, S. Shehab, and L. Liebenberg, "WIP: Introducing Students to Human-Centered Design in a Design for Manufacturability Course," in 2020 ASEE Virtual Conference, 2020, p. 12.
[36] X. S. Apedoe, B. Reynolds, M. R. Ellefson, and C. D. Schunn, "Bringing engineering design into high school science classrooms: The heating/cooling unit," Journal of Science Education and Technology, vol.17, no. 5, pp. 454–465, 2008, doi: 10.1007/s10956-008-9114-6.
[37] L. Deslauriers, L. S. McCarty, K. Miller, K. Callaghan, and G. Kestin, "Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom," Proceedings of the National Academy of Sciences of the United States of America, vol. 116, no. 39, pp. 19251–19257, 2019, doi: 10.1017/pnas.1821935116.
[38] M. Kapur, D. Leigh, and T. Yhing, "Productive failure in mathematical problem solving," Institutional Science, 1717–1722, 2010.
[39] L. S. Vygotsky, *Mind in Society: The Development of Higher Psychological Processes*. Cambridge, MA: Harvard University Press, 1978.
[40] K. Cherry, "What is the zone of proximal development?" *verywellmind.com*, Sept. 11, 2021. [Online]. Available: https://www.verywellmind.com/what-is-the-zone-of-proximal-development-2796034. [Accessed Oct. 15, 2022].
[41] S.D. Sheppard, "Mechanical dissection: An experience in how things work," in Proceedings of the Engineering Education Conference: Curriculum Innovation & Integration, pp. 1–8, 1992.
[42] J. Lamancusa, M. Torres, and V. Kumar, "Learning engineering by product dissection," in ASEE Annual Conference Proceedings: The American Society for Engineering Education, 1996.
[43] M. L. Calderon, "Application of reverse engineering activities in the teaching of engineering design," in International Design Conference. Croatia: Design Education, pp. 1249–1258, 2010.
[44] C. Lauff, D. Kotys-Schwartz, and M. Rentschler, "Design methods used during early stages of product development: Three company cases," in Proceedings of the ASME 2018 International Design Engineering Conference, 2018.
[45] T. Tucker, "Exploring the nature of students' collaborative interactions during a hands-on ill-structured engineering design task," [Master's thesis, University of Illinois Urbana-Champaign], 2021. Available: ideals.illinois.edu.

[46] C. Lauff, D. Knight, D. Kotys-Schwartz, and M. E. Rentschler, “The role of prototypes in communication between stakeholders,” Design Studies, vol. 66, no. 1, pp. 1–34, 2020.
[47] S. Krishnakumar, C. Lauff, C. McComb, C. Berdanier, and J. Menold, “Novice designers’ use of prototypes as communication tools,” in International Conference on Engineering Design, 2021.
[48] B.J. Fishman, W.R. Penuel, A.R. Allen, B.H. Cheng, and N.O.R.A Sabelli, “Design-based implementation research: An emerging model for transforming the relationship of research and practice,” National Society for the Study of Education, vol. 112, no. 2, pp. 136-156, 2013.
[49] S. Shehab, E. Mercier, M. Kersh, G. Juarez, and H. Zhao, “Designing Engineering Tasks for Collaborative Problem Solving,” in Making a Difference—Prioritizing Equity and Access in CSCL: The 12th International Conference on Computer Supported Collaborative Learning, 2017, B.K. Smith, M. Borge, E. Mercier, K.Y. Lim (Eds). Philadelphia: The International Society of the Learning Sciences.
[50] M. Yilmaz, J. Ren, S. Custer, and J. Coleman, “Hands-on summer camp to attract K-12 students to engineering fields,” IEEE Transactions on Education, vol. 53, no. 1, pp. 144—151, 2010.
[51] M. Besterfield-Sacre, C. J. Atman, and L. J. Shuman, “Pittsburgh Freshman Engineering Attitudes Survey,” University of Pittsburgh.
[52] N. Mentzer, K. Becker, and M. Sutton, "Engineering design thinking: High school students' performance and knowledge," Journal of Engineering Education, vol. 104, no. 4, pp. 417–432, 2015.