Community Voices in the Spotlight: Students' Engagement in the Literacies of Human-Centered Engineering Design

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Abstract

Human-centered design is an approach to design that places human needs at the forefront and values the thoughts and experiences of users as crucial elements of the design process. The method provides a framework for addressing *wicked* social problems, from environmental to accessibility issues. In this paper, we present partial findings from an exploratory qualitative case study of disciplinary literacies teaching and learning in an undergraduate project-based engineering course grounded on human-centered design. We focus on the engineering literacies enacted by a team of focal students who collaborated with a local school for visually impaired children to address the problem "How might we increase the accessibility of music to visually impaired people?". Through the qualitative analysis of students' interviews and artifacts, recordings, and observational notes from team meetings, we examine the students' engineering literacies learning. Findings show how students used literacies of human-centered engineering design as tools for centering the perspectives of the recipients of the designed products, unseating traditional top-down design approaches. The paper discusses the potential of human-centered engineering design for 1) supporting and engaging students with community needs as they learn disciplinary practices and 2) advancing social change through the teaching and learning of engineering.

Introduction

Design is recognized by practitioners and educators as an essential attribute of engineering [1], [2]. In recent decades, human-centered design (HCD) has arisen as a method for developing design thinking in engineering. This approach to design places human needs at the center of design processes, valuing users' experiences and perspectives as fundamental for the solutions created [3], [4]. Barlow and Levy-Bencheton describe HCD as "the opposite of the mad scientist scenario, in which a solitary genius working in a laboratory comes up with a revolutionary invention at midnight and unleashes it on an unsuspecting world." [5, p. 97] HCD principles and methods have the potential to address complex social problems [6]. In combination with a social justice perspective, HCD offers a framework to engineer solutions for social issues in diverse areas, such as healthcare, accessibility, and the environment (see examples on IDEO [7]).

Emergent experiences in engineering education suggest the possibilities of HCD for integrating disciplinary learning and socially relevant goals (e.g., [6], [8]). We argue that engaging students in human-centered engineering design projects is a promising alternative to connect engineering learning and social justice through thoughtful attention to communities' needs and experiences. Yet, an essential step for amplifying the method's tools in pre-college and college engineering classrooms is developing research on the disciplinary practices of human-centered engineering design, including their conceptualizations, applications, and pedagogy.

As human constructions, disciplines are social spaces in which knowledge intertwines with norms, cultural conventions, discourses, and social purposes to integrate negotiated disciplinary practices [9], [10], [11]. Central to those practices are the *literacies* or specialized and regular use

of language and texts that *doers* of the discipline share. Recognizing and teaching the specific language and ways of reading, writing, and reasoning with media and texts in any discipline is fundamental to fostering equitable instruction [12], [13].

In this paper, we present part of the preliminary results from an exploratory single qualitative case study of disciplinary literacies practice, teaching, and learning in college engineering. The case study explores the instructional practices and engineering literacies learning in a first-year project-based course grounded on HCD and directed by a professor and engineer who also has practiced this approach in his professional work. The paper focuses on one of our primary research questions: "How and to what extent did the focal engineering students seem to learn engineering literacies while engaged in the academic activities of the course studied?" We analyzed an array of data (interviews, artifacts, recordings, and observational notes from team meetings) to examine the literacies of human-centered engineering design enacted by a team of focal students who collaborated with a local school for visually impaired children.

Theoretical and Empirical Perspectives

We draw on sociocultural perspectives of literacy [14], [15], [16] to conceptualize our work. From this approach, literacies are understood as social practices, always enacted in, embedded, and shaped by the multiple contexts that give them purpose and meaning. The social-practice conception of literacy challenges a traditional, purely cognitive view of literacy as the independent ability to read and write [15]. Moreover, it posits a comprehensive approach that recognizes the multiple forms of literacy and how multiple literacies "only make sense when studied in the context of social and cultural (and we can add historical, political, and economic) practices of which they are but a part." [17, p. 180] From this perspective, *literacy practices* are culturally and socially patterned ways of using texts and language for contextualized purposes [18], [19]. People interacting in disciplinary or professional contexts commonly share unique literacy practices.

The specialized use of literacies as tools of inquiry and communication inside professions and disciplines is the center of disciplinary literacy approaches [20]. Disciplinary literacy scholars agree that students need explicit pedagogical support to learn the literacies of the disciplines in integration with disciplinary knowledge and practice [21], [22], [23], [24], [25]. According to Moje [26], all disciplines engage in common practices, such as problem framing, working with data, reading and writing multiple texts, making and evaluating claims, and communicating findings. However, there are specific nuances. Thus, a common strategy to learn from the professions has been turning to practitioners' literacy practices in search of patterns applicable to classrooms.

In engineering, studies about engineers' literacies come from different research traditions and give a general understanding of patterns of disciplinary activity but do not include human-centered engineering design. Most of the research efforts have originated in composition, rhetorical, and technical communication studies, with a focus on the writing of engineers at different stages of their careers (in industry or academia) in relation to workplace factors (e.g., [27], [28], [29]). Conclusions from this line shed light on disciplinary genre use, as well as communication and writing conventions. Other studies have sought a broader representation of

different literacies, drawing from disciplinary literacy perspectives (e.g., [30], [31], [32]). These authors present some representations of engineers' literacy practices, attending to the specific disciplinary nuances Moje mentioned [26].

Considering the lack of research on the literacies of HCD, we explored a taxonomy of human-centered engineering design literacy practices as part of our case study. Figure 1 summarizes the practices that we present elsewhere [33]. To arrive at this set of literacies, we considered our systematic review of the literature in engineers' literacies and our analysis of the practices enacted and taught by the study focal instructor. The practices can be sequenced in any order and co-occur. Also, the list is not exhaustive. We used this set of literacies as an analytical tool to examine the engineering literacies learning and human-centered engineering design practice of the focal team of students on which we focus this paper.

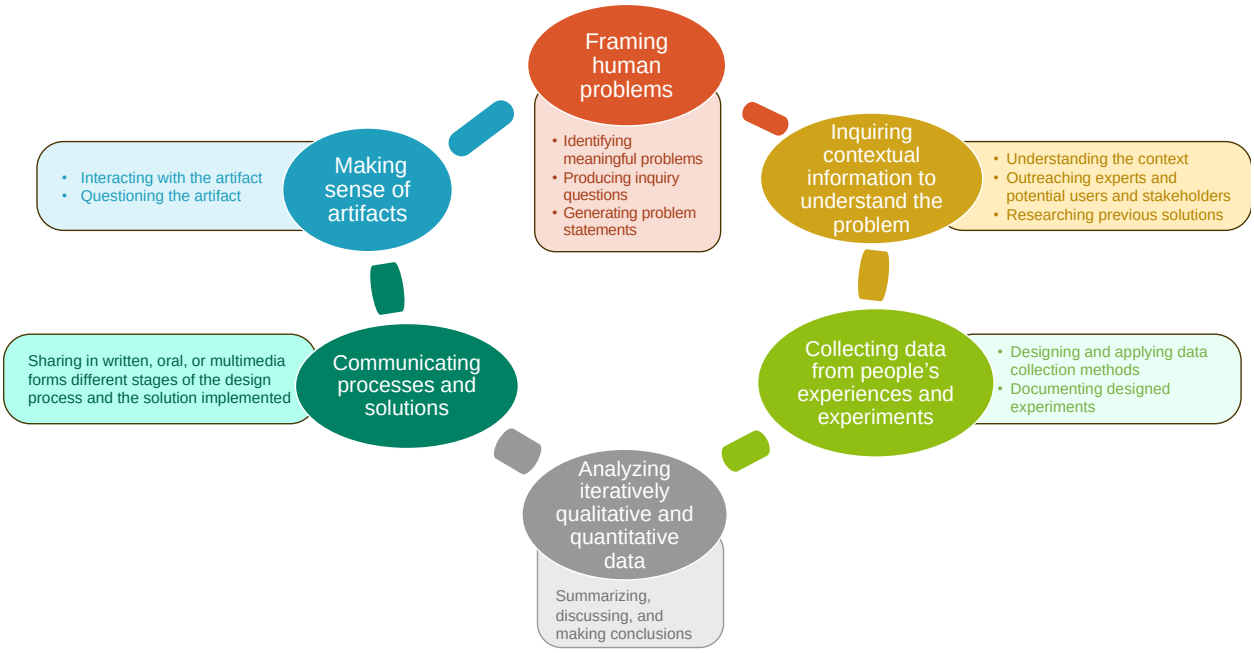

Fig. 1. Human-centered engineering design literacies [33]

Some disciplinary literacy scholars have called for forms of instruction that would support students' participation, critique, and transformation of disciplinary practice to enable their abilities to shape those disciplines [26]. Specific to engineering, Wilson-Lopez and colleagues [32], [34] have called for the study and development of pedagogical approaches that provide students with situated opportunities to explicitly learn their discipline's reading, writing, and language practices while engaged in critical and transformative inquiry. Those calls relate to aspirations in engineering education for transformative instructional practices that change harmful patterns of gatekeeping disengaged instruction—such as those addressed in the studies of persistence from [35], [36]. We claim that a critical approach to the engineering literacies associated with HCD would expand incipient efforts to include a social justice lens in engineering curricula (e.g., [37], [38]) while supporting equitable and transformative disciplinary literacy learning.

The literature on HCD in engineering education shows that the method has recently been considered a tool for achieving socially relevant goals (e.g., [6], [8], [39], [40], [41]). Some of these works emphasize students' experiences in models connecting service learning with HCD [6], [41], [42]. However, as Cardella and colleagues have highlighted, although HCD has the tools for infusing social justice in engineering, the approach "does not automatically lead to a socially just practice or process." [6, p. 14] The study of human-centered engineering design practices, including its literacies, teaching, and learning, is fundamental to advance towards the transformative pedagogies mentioned above. Yet current scholarship on human-centered engineering design has not represented students' learning and practice of the literacies of HCD. Our study contributes to filling that gap.

Method

We report partial findings from a qualitative exploratory single case study centered on the instructional practices and engineering literacies learning in one first-year undergraduate engineering course (ENGR 0716 The Art of Making: Hands-On System Design and Engineering) taught at the University of Pittsburgh's Swanson School of Engineering in Spring 2023. The study research questions were: (1) What were the literacy practices of human-centered engineering design enacted by the focal instructor? (2) How and to what extent did the focal engineering instructor strive to support students' engineering literacies? (3) How and to what extent did the focal engineering students seem to learn engineering literacies while engaged in the academic activities of the course studied? In this paper, we report findings from question 3.

The course was a hands-on, project-based introductory course that featured HCD. The focal participants include the course instructor, Dr. Joseph Samosky, a professor and engineer with ten years of teaching the course, and a team of eight first-year students. The team collaborated with a local school for visually impaired children to address the problem "*How might we increase the accessibility of music to visually impaired people?"* as part of the course's capstone project. We collected data between March and May 2023. Data includes semi-structured in-depth interviews (5.4 hours with the instructor and 1.5 hours with each focal student), observational field notes and audio recordings of classes (including two external events where the students presented), observational field notes and audio recordings of focal students' working meetings, focal students' artifacts, coursework materials and supporting multimedia (pictures and videos).

For our analysis, we followed standard procedures of qualitative case study research (e.g., [43], [44]). For question 3, we used a provisional code [45] based on the set of human-centered engineering design literacies we explored for question 1 (see Fig. 1). We analyzed the different sources of data with potential evidence of students' literacies learning in this order: students' interviews, students' artifacts, classroom observational field notes, team meeting field notes, classroom recordings, and team meeting recordings. The recordings were treated as supplementary data and considered to obtain details when the field notes presented coding. We coded every time we found evidence of the practices. We triangulated across sources to ensure consistency. Table 1 depicts a sample of the codes and related examples from the data.

Table 1. Sample from Coding Scheme

Literacy practice (main code)	**Sub-practice (sub-code) ***	**Sub-practice definition**	**Example from data**
Framing human problems	Generating problem statements	Creating a problem statement that guides research and ideation	"Problem statement: Young students who are visually-impaired struggle to gain a strong foundation in music because the current music education system caters too much to the able and lacks individualization" (Students artifact)
Inquiring contextual information to understand the problem	Outreaching experts	Planning questions for and interviewing people related to the problem. In the case of experts, it is considered experience-based knowledge and privileged closeness with the community involved in the project.	"We did all that by like interviewing with a bunch of people (…) we did like 15 expert interviews and reached out to like 70 people [and] heard back from like 30 over email. So, there's a whole lot of outreach, which was nice, to hear back from a bunch of different people." (Student interview)
Collecting data from people's experiences and experiments	Documenting designed experiments	Designing experiments to test ideas and documenting the experiences of the users.	"The really big set of data came from testing. We went to either 5 or 6 testing sessions, (…) we have a lot of decisions on just like user experience…" (Student interview)
Analyzing iteratively qualitative and quantitative data	Making conclusions	Arriving to conclusions from the qualitative and quantitative data collected before and during testing	"They are discussing the materials, considering the feedback from the last testing. For example, they are making decisions about the light colors and textures." (Observational note from meeting)
Communicating processes and solutions	Sharing in written, oral, or multimedia forms different stages of the design process and the solution implemented. It involves the creation of visual representations (charts, diagrams, graphs) and the production and discussion of evidence-based claims on different media		"As in every Tuesday, teams will present the advances in their capstone projects. Today is special because they have the First Year Conference on Saturday and it's one of the last opportunities for direct feedback." (Observational note from class)
Making sense of artifacts	Interacting with the artifact	Interactively examining the artifact	"Anya [pseudonym**] was the one to write this document because I'm pretty sure this was the very first time, we ever like interacted with the school, because this was when we had first heard back that we needed all our clearances, so we could only do a zoom viewing. So, we just got to watch their classes through zoom…" (Student interview—student reading out-loud an artifact, in this case an observational note they created)

* If applicable **All students' names are pseudonyms

The provisional taxonomy of human-centered engineering literacies was useful in identifying markers of learning in correspondence with the course instructional activities and the engineering literacies supported by the professor, Dr. Samosky.

Findings

Findings show that students learned the literacies of human-centered engineering design to the point of enacting them as tools for centering the needs, experiences, and perspectives of the recipients of the designed products in each step of their project. In consideration of space constraints, we present some exemplary findings.

Framing Meaningful Problems

The problems pursued on HCD come from brainstorming sessions in which the participants are challenged to think about real-world problems where their involvement can make a difference. However, the initial ideas selected generally go through a process of refinement. Problems are iteratively *reframed* in an inquiry process until designers arrive at a relatively stable problem statement. Anya describes the team problem-framing process:

> Over the course of like the next few weeks, like the very beginning weeks, we spent a lot of time trying to narrow down the problem statement because accessible musicianship to blind students can mean a lot of things. It can like-one, the age range of the students can be important. If we're looking at like, elementary or college students. What musicianship is? is also very important. Like, who, what (…) or do they want to have to produce music? compose music? Just playing music? is about the sheet music? or like learning to play by ear? It's all like, there's a lot of different paths we could have gone, but obviously, you don't [have] time to cover…

The process of generating a problem statement includes in-depth team discussions of the different possibilities to address the problem. What stands out in the practice is the role that *considering people* play during the inquiry cycle. As Ben's interview excerpt indicates, *outreach*—the process of contacting individuals related to the topic of study—was necessary for the team's final problem definition.

> So right in the beginning, it was just, 'How do we increase the accessibility of music to visually impaired people?' But as we did outreach, we looked into it (…) which music learning methods were most effective. We learned that there was a lot of focus around the Younger Age group; that's where you develop a lot of the basic methods of thinking, so we wanted to focus more on kids. And that also led us more on focusing on the fundamentals of music instead of like every part in general, because we just wanted to give them that step in the right direction that sets them up for being interested in that.

The phrase that Dr. Samosky recalls in several classes, "We start with people, and we design to answer people's needs," permeates the practice from the selection of a meaningful problem to its narrowed final inquiry statement, including the main inquiry question:

> Young students who are visually-impaired struggle to gain a strong foundation in music because the current music education system caters too much to the able and lacks individualization. How might we better introduce students who are visually impaired to the foundations of music? (focal students' problem statement; retrieved from students' presentation)

In the case of the focal students' problem statement, the wording denotes the relevance placed for the social problem of lack of accessibility that children with visual impairments face.

Inquiring Contextual Information as a Tool to Deepen Understanding of the Problem

As part of *inquiring contextual information to understand the problem*, HCD promotes *outreach*. The focal team documented contacting 71 individuals related to their problem space (musicians with visual impairments, music teachers of visual-impaired students, music teachers, professors of music, and amateur musicians with visual impairments or low vision), hearing back from 36, and interviewing 15. Ella refers to their outreach phase in the following excerpt:

> So in the outreach stage, it was basically like cold email as many people as you can (…), because if you can land an interview, [it's] 10% of the time (…) It was difficult because it's very hard to find people who either have experience working with visually impaired musicians or just, are visually impaired musicians themselves. Because the whole problem we're trying to solve is the fact that (…) the education system is messed up, and, as a result, we don't see enough of them (…), but we kind of compiled all the evidence together (…). We valued the opinions of visually impaired musicians a little bit higher because, you know, they've actually had experience, and we were able to kind of like of break that down into general subject areas that need improvement…

The process implies a series of literacy practices, such as creating formal emails for contacting professionals, generating interview protocols, and planning activities. Before and during the development of the interviews, students engaged in the review of bibliographical sources for contextual cues and the state-of-the-art (previous solutions). The interview protocols conveyed their initial revision of sources. For example, they included questions for different potential interviewees, such as: *If you have had experience teaching visually impaired students, what techniques did you use to teach them? What techniques do you think worked the best? What are your thoughts on braille Music Code? What options do you think are the best for musicians with visual impairments? What are your thoughts on the current options available to visually impaired students and musicians?*

Members of the focal team also mentioned drawing from particular studies. Ella, for instance, mentioned one that concluded: "visually impaired students are like 4,000 times more likely to have perfect pitch." She referenced that study because it confirmed information received in one interview with a music teacher with experience teaching visually impaired students. However, following the spirit of the method, students considered written sources secondary to interviewers' insights. Also, as Ella's excerpt above suggests, they privileged experts with experiential knowledge (e.g., visually impaired musicians and teachers of kids with visual impairments). The interviews suggest a critical reading and analysis of sources guided by the principles of HCD. Students valued the knowledge from written sources as a base for understanding the experiences of people related to the stakeholder community that give real meaning to their inquiry.

The undergraduates also had to work with the data resulting from outreach and the revision of bibliographical sources in a short period of time. They used their data analyses to make decisions for advancing their capstone project. For example, they learned about the problems of braille music code— "It doesn't teach you how to play music, or an instrument, or give you any methods (…) there are two different codes, so they can be confused", in the words of Jonas— through this process and then applied that to the construction of their prototypes. In sum, the literacies associated with *Inquiring Contextual Information* give the focal students tools to understand their problem better and refine the initial goals of their project.

Focus On Users Informing Data Collection and Testing

A fundamental literacy practice in HCD is *Collecting data from people's experiences and experiments*. Different genres interact during data documentation practices, such as interview protocols, surveys, consent and cover letters, field notes, memos, and data collection plans. To document the children's experiences with music, the focal team of students first created interview protocols, interviewed teachers from the school for visually impaired students, prepared summaries from the interviews, and took field notes of class observations. Of saliency are the observational notes that the team generated from Zoom observations before obtaining their clearances to enter the school.

The literacies applied to the data collection of users' experiences in the early stages of ideation, combined with the literacies related to inquiring contextual information, were essential tools for developing prototypes and their preceding *pretotypes*—name given to the very first prototypes in a human-centered design project, which are usually constructed with low-cost materials, like paper and cardboard. Once the team created the first *pretotypes*, they started an iterative cycle of testing-documentation-improvement-testing. During those processes, students documented the kids' interactions with their successive improved designs and surveyed teachers' and teaching aids' perspectives about it. They created additional artifacts for this stage, such as data collection sheets for each prototype and test session. The team used the information gathered to make data-driven decisions. In total, students documented 16 hours of testing, with 48 students in 19 classrooms. They also collected comments or interviewed 40 school staff. The following excerpt from one of Ben's interviews illustrates how relevant the users' experiences and perspectives were to their creations:

> So (…) we would maybe go test on, like, a Monday or a Thursday, and then the next day we immediately group and kind of discuss what has happened in that testing period. So maybe, we would [have] heard that our initial box [prototype A] had like 8 keys on it, so like a whole octave, but the teachers and kids and the aids all were like 'that's too complicated.' So, we like right away, cut it down to having those 3 initially, so that it was just a step away, for the kids to have a first understanding, and then for the music (…) the motion detector [prototype B], oh, and the box as well, (...) We didn't know initially (…) but not all the kids are fully blind, so for those who are just slightly visually impaired the light, it's just like a really good cue, so we added the light to the movement to (…) associate the connection between their movement and what's happening around them, whether that's in the music and the light (…) And that was one of the things that we heard back from a couple of our first meetings, that the lights are actually really important."

The students had three main objectives for their prototypes (*build connections, enjoyability, and accessibility*). In addition to the oral information received from the participants, the team documented the kids' interaction with the prototypes in relation to those goals. Anya here explains the process regarding the first objective:

> So collecting data is really hard because, ultimately, what we're trying to do is assess learning. And how do you assess learning, especially when it comes to music? (…) So we ended up coming up [with design goals] (…) First of all, we wanted to see if it was actually helping people make connections. In order to do that, we would usually ask them [the students], we would let them play around with it [the prototypes] for a while. We would go, 'Hey? Can you play me a low note', or 'can you? Can you press the Red Triangle?' [in students with low vision] And if they could do that,

> that would count as a connection made, and we would measure it like this, 'many people did this, many people didn't,' so we took a percentage. That was the most important criteria [sic] because that was the main goal...

A fundamental part of any team meeting was the technical discussion of the prototypes. Before engaging in detail about materials, programming, and electrical connections, students always discussed the data collected from the last testing sessions. As our analysis suggests, the literacies applied to data documentation enabled them to answer their questions, advance in the technical elements of their prototypes, and ultimately make decisions that close the design cycle, constantly building over users' experiences.

Highlighting Users' Experiences and Perspectives in the Communication of Processes and Solutions

During the course, students had to create multiple devices to communicate their processes and solutions to others: presentation slides, visual representations (charts, diagrams, figures), pitch scripts, video storyboards, videos, posters, and webpages. Additionally, the team constantly generated artifacts for internal communication: meeting agendas, meeting memos, *to-do* lists, and organizational plans.

In producing the diverse multimedia texts required for their project, students skillfully applied their literacy learning—supported by the instructional structure of the course—to leverage the principles of HCD, particularly the central role of users and the social dimension of the problem. For instance, their project's pitch scripts and presentations included contingent information to present their problem, such as "9 in 10 children want to learn an instrument" and "11.7M children are visually impaired." The team also included an analysis of the disadvantages of existent solutions (for example, the expensive cost of a device) and, in oral presentations on events with the general public (a *First-year conference* and an *Engineering Exposition*), an explanation of the difficulties of learning braille music code supported by physical artifacts in braille.

The implementation of the literacies related to the communication of processes and solutions in HCD relies on *examining and evaluating arguments* and s*ustaining and communicating claims*. Regarding the former practice, each week, course students engaged in the presentation of the advances in their projects. After each group, Dr. Samosky facilitated a moment of feedback in which students and teacher assistants participated orally or through sticky notes. Those moments had a positive tone that encouraged students to recognize progress and suggest improvements. At the same time, they were venues for building critical capacities for the interrogation and evaluation of claims. The members of the focal team contributed to the feedback instances, discussed the week's feedback as the primary point of their meeting agendas, and seriously considered every suggestion resulting from their presentations.

Finally, sustaining and communicating claims based on evidence is not only a literacy practice but also a learning outcome in engineering. Students exercised this practice through each step of the process, especially after analyzing data and implementing changes in their prototypes, because every modification required being warranted in evidence. They also sustained claims in every artifact they created to share their project. Some of the students' claims are a powerful

demonstration of the connections they made with the community and the social justice dimension of HCD. The following excerpt is an example of those claims; it is part of Ella's answer to a question about her central claims after finishing the project:

> So definitely, the first claim is that these kids are fully capable of becoming phenomenal musicians (…). Second, is that you can. Definitely. This is less related to the projects and more related to, just like, design in general. It doesn't take much to make a small change in the lives of people around you. We generally think that we can't and (…) People will lose motivation because they feel like they can't enact any real change in other people's lives, but in just under the span of 6 separate testing sessions, we have sort of made the lives of these kids better, if only for like an hour or two. And that is just a few steps on the road to like something much bigger, and it goes to show that you, even one person, can have an impact. And if so many people can work together like, you could probably change, I don't know if you could change the world, but you could change your city, you could change your local government…

Conclusions

In this paper, we asked: "How and to what extent do the focal engineering students seem to learn engineering literacies while engaged in the academic activities of the course studied?" Our data suggest that students' learning of the literacies of HCD is reflected through the different stages of their capstone project. Moreover, they used the literacies as tools for honoring the voices and experiences of the community where they implemented their project.

Our study offers implications for engineering education. Foremost, although not directly the object of this paper, it is impossible to understand learning without considering teaching. In a phenomenographic study, Zoltowski et al.[46] argue that students' ways of understanding and experiencing HCD have different degrees of comprehensiveness. Our data show that focal students seem to present a comprehensive perspective of HCD:

> The main issue with the current system is that, quote-unquote, it lacks individualization. And so, the whole principle behind human-centered design is that we get to know the people who are ultimately going to be using these products, and we talked to them directly, and we asked them for feedback, and that was really important, and ended up becoming a major player in how our entities [final prototypes] looked. (Ella)

Zoltowski and colleagues concluded that a more comprehensive understanding is critically impacted by immersive experiences with real users. Based on our case study, we contend that teaching is also (or even more) a fundamental force. Dr. Samosky challenged traditional hierarchical teaching and design perspectives in engineering, explicitly supporting students' navigation and learning of engineering disciplinary practices, including literacies. Students' learning of HCD and its literacies was mediated by the carefully curated instructional philosophy (*Hands-on*), structure, preparation, and execution of the course.

Finally, although affected by the natural limitations of a single case study, our findings support the case for extending the study of literacies and other disciplinary practices in engineering education. Acknowledging the relevance of HCD for social justice in engineering education, studies in this line can contribute concrete tools for teaching and learning. For instance,

community-engaged educators can build over the literacies of human-centered engineering design to better support disciplinary learning and student engagement with their communities.

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