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# Changes to stakeholder engagement approaches throughout a capstone engineering design course

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**Abstract**
Stakeholder engagement activities are essential for guiding designers' decision-making throughout their design processes. In capstone courses, engineering student designers practice engaging with stakeholders in preparation for their professional careers. However, understandings of (1) how engineering students engage stakeholders to inform design decisions and (2) the factors that lead students to change their engagement approaches over a single project are limited. Our study investigated capstone design teams' interactions with stakeholders at early, middle, and end stages of the capstone course by analyzing interview transcripts and design reports to develop narratives of interactions for seven teams. Comparisons among teams across their capstone course revealed fundamental differences in what drove students toward or away from stakeholder engagement. Our findings highlighted several factors related to design team characteristics and project context that can inform future design pedagogy as well as the development of curricular design projects that provide effective environments for students to practice more human-centered design approaches.

**Keywords** Design · Human-centered design · Stakeholder engagement · Information gathering

## Introduction

Stakeholder engagement is a core aspect of several design philosophies, such as human-centered design, that center the societal impacts and implications of design solutions (Krippendorff, 2007; Steen, 2012; Zhang & Dong, 2009). Engineering designers engage with stakeholders, i.e., individuals who may be directly or indirectly affected by project outcomes, to develop deeper contextual understandings of design problems and to solicit feedback on solution concepts, among many other reasons (Coleman et al., 2016; Dieter & Schmidt, 2012; Ulrich & Eppinger, 2012). Stakeholder engagement activities may take a variety of forms, ranging from one-on-one interviews (Agarwal & Tanniru, 1990; Kouprie

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& Sleeswijk Visser, 2009; Mazzurco et al., 2018) to collaborative design workshops (Aguirre et al., 2017; Mazzurco et al., 2018).

Studies show that engaging with stakeholders can help engineering student designers develop more valid stakeholder requirements (Mohedas et al., 2015) and more appropriate solution concepts (van Rijn et al., 2011). Previous studies have also identified several challenges that engineering students may encounter when engaging with stakeholders (Bano et al., 2019; Loweth, Daly, Hortop, et al., 2020; Mohedas et al., 2014a) and applying stakeholder information to inform their design decisions (Guanes et al., 2022; Mohedas et al., 2014a; Sugar, 2001). These challenges, as well as other factors such as engineering students' perceptions of the value of stakeholder engagement (Loweth et al., 2019; Loweth, Daly, Hortop, et al., 2021; Zoltowski et al., 2012), likely influence how engineering student designers choose to approach stakeholder engagement activities as part of their design projects. However, few studies have explored in depth the rationale behind engineering students' stakeholder engagement approaches and the factors that may lead students to change their approaches over the course of a single design project. To address this research gap, our study investigated how seven student design teams conceptualized and changed their stakeholder engagement approaches over the span of a single-semester mechanical engineering capstone design course.

## Background

Prior literature has highlighted several factors that seem to influence how engineering student designers approach stakeholder engagement activities as part of their design projects. One factor relates to students' perspectives on stakeholder engagement. For example, as described by Zoltowski et al. (2012), some engineering students may view stakeholder engagement in their design projects as essential, while other students may view such engagement as unnecessary. Work by Loweth et al. (2019; 2021) further suggests that engineering students that value stakeholder perspectives may be more likely to solicit these perspectives to inform their projects. However, engineering student designers may struggle to recognize the importance of stakeholder engagement for informing design decisions due to the technocentric focus of standard engineering education, which positions considerations of social context as tangential to technical engineering work (Cech, 2014; Niles et al., 2020). Research shows that this technocentric focus negatively impacts engineering students' abilities to conceptualize the broader societal contexts of their design projects (Mazzurco & Daniel, 2020) and may lead them to form narrow understandings of the more socially-engaged aspects of engineering work (Loweth, Daly, Paborsky, et al., 2021).

Even when engineering students value stakeholder perspectives, there may be other factors that constrain their abilities to engage with stakeholders in practice. For instance, engineering students may encounter difficulties identifying stakeholders that can provide relevant design information, and as a result may solicit fewer stakeholder perspectives than initially intended Mohedas et al.,( 2014a; 2014b). Hui et al. (2014) and Loweth, Daly, Liu et al. (2020) have also described challenges, such as geographic distance and time constraints, that engineering student designers may encounter related to accessing relevant stakeholders. Course requirements and constraints may also incentivize engineering students in curricular design contexts to prioritize the perspectives of their instructors when making design decisions (Dannels, 2000; Guanes et al., 2022). Engineering students might choose to interact with fewer stakeholders as a result.

In addition, challenges that engineering student designers encounter during their stakeholder interactions may also potentially influence their stakeholder engagement approaches. Previous studies indicate that engineering student designers may struggle to ask effective, open-ended questions to solicit relevant design information from stakeholders (Bano et al., 2019; Loweth, Daly, Hortop et al., 2020) and may struggle to adopt language that is understandable to stakeholders (Loweth, Daly, Hortop et al., 2020; Luck, 2007; Mohedas et al., 2014a). Engineering students may also struggle to interpret the more subjective aspects of stakeholder responses and/or navigate contradictions in the information provided by different stakeholders (Mohedas et al., 2014a, 2020). Furthermore, students may struggle to identify concrete ways to apply information from stakeholders to their design projects (Mohedas et al., 2014a, 2020; Sugar, 2001). These challenges may influence the degree to which engineering student designers view their stakeholder interactions as contributing useful information, and thus their willingness to conduct further interactions.

Lastly, research shows that engineering student designers tend to change their approaches to stakeholder engagement over the course of their projects. For instance, Lai et al. (2010) and Loweth, Daly, Hortop et al. (2021) both observed that engineering student designers in curricular design contexts conducted the majority of their stakeholder interactions during early project stages, with fewer interactions occurring in later project stages. Rao et al. (2021), in their study of engineering student designers' decision-making strategies, also found that their participants mainly considered users as part of their early-stage design decisions and less so as part of later-stage decisions. Timing within the larger design project thus represents another factor that may influence engineering students' stakeholder engagement approaches as well.

While previous studies have identified several factors that may influence how engineering student designers approach stakeholder engagement activities, it is unclear how these various factors intersect and affect student approaches in practice. For example, Loweth et al. (2019, 2021) observed that engineering student designers possessed differing perspectives on stakeholder engagement and also varied their engagement approaches over time. However, these studies did not directly investigate the connection between factors, i.e., they did not investigate *how* engineering student designers chose a certain engagement approach or *why* they changed approaches over time. Addressing this research gap is important because there may be factors, such as the limited accessibility of stakeholders, that negatively influence how engineering students conceptualize or approach stakeholder engagement activities yet could be easily addressed by design instructors. Deep qualitative data related to engineering student designers' perceptions of their stakeholder engagement activities is also needed to develop more comprehensive understandings of how students develop their perceptions of stakeholder engagement and, in turn, how student' perceptions influence the ways that they engage with stakeholders in practice.

**Table 1** Characteristics of student participants

| Characteristic | # Participants |
|---|---|
| Sex | |
| Male | 23 |
| Female | 5 |
| Academic major | |
| Mechanical engineering | 26 |
| Biomedical engineering | 2 |
| Prior design experience (# design courses) | |
| Three | 23 |
| Four | 5 |

**Table 2** Capstone design team project descriptions

| |
|---|
| Team 1 (Sponsored by a biomedical engineering professor): Design a piece of laboratory equipment for a research laboratory within biomedical engineering |
| Team 2 (Sponsored by a mechanical engineering professor and physicians from a West African country): Design a consumer medical device for use by pregnant women in a West African country |
| Team 3 (Sponsored by an international durable goods company): Design a consumer product |
| Team 4 (Sponsored by a mechanical engineering professor): Design a piece of laboratory equipment for a mechanical engineering research laboratory |
| Team 5 (Sponsored by a physician at a medical school): Design a consumer product for pregnant women |
| Team 6 (Sponsored by a non-government organization: Design a diagnostic device for community health-care workers in a West African country |
| Team 7 (Sponsored by a mechanical engineering professor and physicians from a West African country): Design a medical simulator for use in a West African country |

## Research design

### Research questions

Our study was guided by the following research questions:

1. How do engineering student design teams engage stakeholders throughout a capstone design course?
2. How do their stakeholder engagement approaches change throughout the design course? What factors motivate these changes?

### Participants and context

Our participants included seven undergraduate student teams, with four students per team, totaling 28 students. The teams were enrolled in a single-semester mechanical engineering capstone design course at a large Midwestern university. Teams were invited to participate through an email sent to all students in the capstone course. Teams were eligible and selected to participate if at least three out of four team members agreed to be study participants. Summative data about participants are included in Table 1. Race and ethnicity data were not collected.

As part of the capstone design course, student teams were tasked with developing a prototype to solve a unique design problem experienced by a sponsor or sponsoring organization, with each team working on a different project. These projects reflected a range of project types, such as medical device design and consumer product design. Team projects and sponsors are described in Table 2.

All students attended the same weekly lectures, which included topics ranging from problem definition and stakeholder engagement to solution development and evaluation. Teams also completed four design reviews (DR) throughout the semester. DR1 included information gathering for the purposes of problem definition and requirements development. DR2 included concept exploration and selection. DR3 included engineering analysis and iteration. DR4 included verification and validation of a functional prototype. Each team was mentored by one of three mechanical engineering faculty, who was additionally responsible for grading the design reviews submitted by teams. Teams 1 and 4 shared a faculty mentor, who was also a member of our research team. Teams 2, 5, 6, and 7 also shared a faculty member. Team 3 did not share a mentor with other teams in this study. None of these mentors were also design team sponsors. Besides one member of our research team who served as a faculty mentor to two of the teams, none of the other study team members had a role in the capstone design course.

## Data collection

We used a constructivist qualitative research approach to understand stakeholder engagement experiences of the participating design teams from their perspectives. Data sources included multiple means to understand when and how teams engaged with stakeholders during their design work as well as how teams felt those interactions impacted their design decisions.

We conducted four semi-structured group interviews with each participating team. These interviews typically lasted between 40 and 70 min and coincided with the four design reviews required by the capstone course. Initial interview protocols were developed following recommended practices for semi-structured protocol development (Leydens et al., 2004; Maxwell, 2013) and were piloted with a capstone design team that was not part of our study.

Each interview followed a similar overall structure, which was guided from the perspective that design is a decision-making process (Hatamura, 2006). By exploring the decisions that led participating teams to their final design, we aimed to reveal information that each participating team believed was relevant in their design processes. We asked participants about their design decisions broadly first, then followed up on information about stakeholder engagement activities specifically if the information emerged. This approach was informed by prior research showing that engineering student designers, when asked directly, may sometimes claim that stakeholder interactions significantly affected their design outcomes, despite limited documented evidence of stakeholders information impacting their design decisions in their design reports (Sugar, 2001). By focusing our protocol on participating teams' design decisions, we sought to elicit authentic information about the ways that stakeholder engagement activities contributed to their projects. Additionally, as we asked questions about decisions at key points in their processes,

**Table 3** Example questions from protocols developed for design team group interviews

| Interview | Example Questions |
|---|---|
| Interview 1 (after first design review) | What is the goal of your project?<br>Tell me in general how you developed product requirements<br>Follow-up Questions: Where did they come from? What information did you use? Where did this information come from?<br>Let's pick a specific user requirement and talk about it in detail. Where did this user requirement arise from? How was it developed? What information did you use to generate the requirement? |
| Interview 2 (after second design review) | First, let's go over your product requirements to date. Here are the product requirements you had during the first design review and the updated list for the second design review. Could you go over the changes you made to the requirements and why those changes were made?<br>What methods or information did you use/gather to decide on a final concept? How did you arrive at this idea or information source? |
| Interview 3 (after third design review) | Did your team make any changes to product requirements or engineering specifications?<br>Follow-up Questions: Was new information involved in the change? Where did this new information come from? Was this change important?<br>How did you choose the components or systems to perform the engineering analysis?<br>What information did you gather to make this decision? From what sources? |
| Interview 4 (after fourth design review) | Do you think your final design was successful? Why or why not?<br>What aspects make it most successful?<br>What design tools did your team find most useful during the semester?<br>Follow-up Questions: What decisions did they specifically help you make?<br>How would you proceed if you were to keep working on the project long-term? |
| Across all interviews<br>These example follow-up questions were used across all interviews when a stakeholder was mentioned | You mentioned [stakeholder name], what did you speak with them about?<br>How did you engage with them (e.g. in person, over the phone, via email, etc.)?<br>What questions did you ask? What were you hoping to learn?<br>What information did they provide? Did it influence your [current design decision]? If so, how? If not, why?<br>Did you follow-up with [stakeholder name] after the initial engagement?<br>Was the interaction useful in making the [design decision]? If so, to what extent? How did you synthesize the information obtained from the stakeholder with the other information you had at hand? |

we hoped to limit challenges participating teams could have in recalling stakeholder information that contributed to their decisions.

We also tailored our protocols to each team throughout the semester based on the information provided in each team's design reports to ensure that we comprehensively explored the design decisions made by each team throughout the semester. In other words, when the teams indicated they had made a particular decision, we asked in the interview about how they made that decision. Table 3 displays example questions from each interview session, which were focused on the design decisions made during that section of the project. Additionally, Table 3 also displays questions that were asked once a team named a stakeholder as a source of information they gathered. For example, if in the answer to the prompt "Tell me how you developed product requirements," students mentioned end-users, then we used the follow-up questions, listed at the bottom of Table 3, to probe deeper into the engagement the students had with their end-user. This interview and follow-up approach allowed us to ask questions in a uniform way and learn about unique stakeholder interactions by each team.

In addition, each participant completed a survey at the beginning and end of the capstone course. The pre- and post-course surveys contained the same open-ended questions, such as "What role do you think stakeholders should have during product design?" and "Identify challenges to interacting with stakeholders when designing." We used these survey data to clarify if and how individual participants' perspectives on stakeholder engagement changed over the capstone course.

## Data analysis

Our analysis process focused on teams as the unit of analysis. First, two members of the research team reviewed transcripts of design team interviews to identify specific segments where participating teams discussed interactions with design stakeholders. These were straightforward to identify as design teams were asked to name any interactions they had at each stage of the design work. Stakeholder interactions included in-person interviews (which was the most common form of engagement), phone calls, and emails. Experts (who were not end-users) and course instructors were not included as stakeholders in this round of analysis. The two researchers compared each identified interaction in their separately analyzed transcripts and reached complete negotiated agreement as to the stakeholder interactions present in the data set. The final list of stakeholder interactions included 110 instances across the seven participating teams.

After compiling the list of stakeholder interactions, we separated interactions by team and by interview (which followed each Design Review). We then summarized the stakeholder interactions described by each team in each of their interviews. Then, we combined these summaries of each interview with information from teams' design reports and surveys, where teams described if and how stakeholder interactions affected specific design decisions and the overall direction of the team's design project, to craft two-page narratives of each team's experience interacting with stakeholders throughout their projects, following recommendations by Creswell and Poth (2016) on summarizing data as narratives. In the narrative, we included consistent information for each stakeholder interaction, which was reported directly by participating teams: with whom the interaction occurred, why the interaction took place, what methods were used during this interaction, what information was gained from the interaction, how the interaction affected design decisions, whether the teams found the interaction useful and why, and if the interaction affected how they planned to proceed with stakeholder engagement. All stakeholder interactions reported in any data source were included in the narratives, allowing us to understand each team's stakeholder engagement approaches over the course of their design projects.

Once the narratives were developed, we described each team's engagement with stakeholders during their design projects. Two researchers separately read each narrative and described the roles of design team factors (e.g., preparation, motivation, perceptions of stakeholder engagement) and contextual factors (e.g., availability of stakeholders, design phase, type of stakeholder, communication method) on how participants approached their stakeholder engagement activities. The process for generating these connections between factors and approach were by creating links in the data; for example, "the team said the problem was defined well and did not need further information, thus the team did not seek out information from stakeholders in understanding their design problem." We also analyzed whether design teams changed their perceptions of, approaches to, or uses of stakeholder engagement over the semester and whether these changes could be attributed to specific factors. The language we used to name the causal factors that we identified in our analysis were informed in part by prior literature (Loweth, Daly, Liu, et al., 2020; Mohedas et al., 2014a; Zoltowski et al., 2012). The collection of factors and stakeholder engagements for each team were considered a characterization of how the team engaged with stakeholders during their design projects. After independent characterizations were created by the two researchers, they discussed their characterizations and came to a consensus about how to describe how design decisions were affected by stakeholder engagement during the design project. Finally, after characterizing each team independently, we compared our descriptions of stakeholder engagement approaches across teams. This comparison helped to identify common and distinct approaches to stakeholder engagement and prompted us to add clarifications to the characterizations.

## Research team positionality

The four members of our research team all occupied social positions as instructors or design team mentors for prior offerings of capstone or other design courses and have experience teaching engineering students how to engage stakeholders in curricular and co-curricular contexts. This social position informed the motivation for our study and how we formulated our research questions. Through answering our first research question, our goal was to identify students' successful stakeholder engagement practices, which we might encourage through our pedagogies, as well as potential knowledge gaps that we might address. Through answering our second research question, we sought to identify and clarify factors that influenced students' approaches that, as instructors, we had power to change in our curricular environments to encourage more effective design behaviors. Our data collection approach was informed by our deep familiarity with the mechanical engineering capstone course from which we recruited participants. Our data analysis approach was informed by our training as qualitative design education researchers and our expertise related to stakeholder engagement in particular. Based on our prior work and knowledge, we recognized that the factors that affect engineering students' approaches to stakeholder engagement may exist at multiple levels of interaction (e.g., interpersonal vs curricular) and across multiple time scales and may have multiple effects. Thus, relevant factors may not emerge within a single interview, and their effects may not be clear even across multiple interviews. Our goals in constructing narratives of each team's stakeholder engagement experiences from multiple data sources were 1) to reveal factors that potentially existed beyond single interactions or student experiences, 2) to triangulate factors across data sources to confirm their validity, and 3) to illustrate how factors impacted student approaches.

## Findings

In assessing our first research question, we found that participating teams varied in both their approach and the extent to which they engaged with stakeholders throughout their capstone design projects. Teams ranged from minimal engagement with stakeholders (only interacting with their sponsors) to extensive engagement with stakeholders (actively reaching out to many diverse stakeholders multiple times during the semester). We summarize participating teams' overall approaches in Table 4.

Each team's approach was distinct, and the motivations for these differences were evident in the analysis of the narratives. Descriptions of these differing motivations are described as key factors that affected teams' levels of stakeholder, addressing our second research question. A variety of factors contributed to the extent and the nature of stakeholder engagement including: the perceived number and diversity of relevant stakeholders, the extent to which a project was well-defined during the early stages of the course, the student team's domain knowledge relative to their perception of the stakeholders' domain knowledge, the team's motivation to engage in human-centered design, the extent to which teams struggled to synthesize stakeholder information, and the perceived quality and/or applicability of stakeholder information to design decisions. We organized the findings by these factors, highlighting several teams to illustrate how their particular approaches differed from other terms and changed throughout the semester. Teams with contrasting or similar projects or design processes are presented in pairs to better exemplify how design team factors and contextual factors affected how teams engaged with stakeholders throughout the course and how stakeholder engagement impacted their design decisions. Team 3 is discussed separately as neither their process nor their project had a key factor that distinguished or linked them to the other teams.

### Teams 1 & 4: engagement factor—level of initial project definition

Teams 1 and 4 were both designing laboratory equipment for research labs on campus. However, their level of and approach to stakeholder interactions differed greatly. While Team 1 decreased their level of engagement with stakeholders over time, Team 4 increased their engagement with stakeholders. Team 1 also interacted minimally with their end-users and sponsors. By comparison, Team 4 interacted extensively with their end-users and sponsors and discussed how engaging with stakeholders was a major component and challenge during their design project.

One significant factor that seemed to explain the observed difference in engagement approaches between Teams 1 and 4 was the level of definition for each team's project at the beginning of the semester. Team 4's project was ill-defined and its various end-users had different ideas of what the project should accomplish:

> "Problem definition was the [most difficult] stage… [the sponsor] was really vague… they didn't know what they wanted… [the end-users] didn't agree with each other.

**Table 4** Overview of team's engagement with stakeholder during semester

| | Project | Sponsor | Initial interactions | Mid semester interactions | End of semester reflections |
|---|---|---|---|---|---|
| Team 1 | Laboratory equipment | Biomedical engineering laboratory | Sponsor had well-defined, clear idea of what the project needed to accomplish. Sponsor laid out the product requirements for the team and significantly reduced the work required during initial phases. | Team 1 began to encounter challenges when the sponsor changed her mind about the required capabilities of the design. | Team 1 faced delays at the end of the semester related to the changing requirements because the sponsor and end-user were not fully aware of the design course expectations. The team acknowledged that at the beginning of the semester its interactions with the sponsor might not have been ideal: "*We were … trying to get our bearings, so we weren't able to ask them a lot of the more in depth questions.*" |
| Team 4 | Laboratory equipment | Mechanical engineering laboratory | Sponsor was a professor in mechanical engineering. Significant conflicts arose among the end-users (who were graduate student researchers) about the product requirements. The design team had to conduct extensive interviews and group discussions to finalize the requirements and engineering specifications. | Team 4 worked through the conflicting needs of its stakeholders by developing better communication strategies such as using group interviews instead of individual interviews. | Team 4 developed a successful prototype and delivered it to the sponsor. The team recognized to a much greater extent the importance of stakeholder interaction during design. One member said, "*Stakeholders should provide the requirements and some specifications … They should be able to have input on design selection and should be able to refine their expectations throughout the design process.*" |

**Table 4** (continued)

| | Project | Sponsor | Initial interactions | Mid semester interactions | End of semester reflections |
|---|---|---|---|---|---|
| Team 5 | Consumer medical device | Medical school professor | Team 5 began with the view that the sponsor (medical doctor) was the key stakeholder in the design process and relied on the physician to provide all of the requirements. | Team 5 continued to rely on the sponsor for most design decisions until the course instructor told members to interact with end-users. Interacting with the end-users, which occurred after developing a full prototype, revealed major design problems and forced a significant shift in the final concept. | Team 5 underwent a change in attitude regarding stakeholder engagement. One member said, "*When a prototype is developed, it should be presented to stakeholders… checking in with stakeholders during the design process ensures that the product is on track with their needs.*" |
| Team 7 | Medical simulator | Physicians at partner hospital | Team 7 selected the project after two months of immersion in a hospital located in a low-income setting prior to the start of the course. During the initial design process, Team 7 gathered as much information as possible from a diverse set of stakeholders, focusing on experts in the medical field. | Team 7 continued to interact extensively with stakeholders as the design process progressed. Members transitioned from gathering background and requirements information from stakeholders to interacting with stakeholders to validate the team's design decisions and confirm analyses. | Team 7 began and ended the semester with a human-centered view of the design process. One member said, "*Stakeholders should be a huge source of information in the design process. It is important that the needs and wants of the stakeholders are clearly understood so that the designers can evaluate, work, and change with [stakeholders'] ideas in mind.*" |

**Table 4** (continued)

| | Project | Sponsor | Initial interactions | Mid semester interactions | End of semester reflections |
|---|---|---|---|---|---|
| Team 2 | Medical diagnostic device | Clinician | Team 2 selected its project after having performed two months of immersion in a hospital located in a low-income setting prior to the start of the design course. During the course, Team 2 focused on gathering information from US physicians to compare to the information gathered during the immersion experience. | The information Team 2 gathered from domestic doctors conflicted with the information obtained from clinicians in the low-income settings. As a result, the team reduced their interactions with stakeholders as the semester progressed. | Team 2 focused on engineering-based validation of the design without stakeholder engagement. |
| Team 6 | Medical diagnostic device | Non-governmental organization | Team 6 began by consulting with diverse stakeholders, particularly clinicians with diagnostic expertise. The team had difficulty translating the information into something tangible. | Team 6 re-engaged with physicians during concept generation, but did not obtain information that they deemed helpful to the project. Team 6 began to rely more on published literature to make decisions and they engaged less with stakeholders. | Team 6 concentrated on the technical aspects of the project and did not have significant engagements with stakeholders after the mid-point in the semester. |

**Table 4** (continued)

| | Project | Sponsor | Initial interactions | Mid semester interactions | End of semester reflections |
|---|---|---|---|---|---|
| Team 3 | Consumer product | Durable goods company | Sponsor had well-defined overall project goal (reduce the cost of manufacture for one of their products). The sponsor was able to provide general qualitative information with respect to their requirements, but did not provide the information the team thought they needed to develop engineering specifications. | Team 3 encountered logistical challenges with respect to communicating with their sponsor. The team felt that they were not provided with critical project-relevant information, but also did not seek this information out from other sources. | Team 3 eventually realized that some of their original assumptions (based off of the qualitative information provided by their sponsor) were not accurate. The quantitative data they sought from their sponsor arrived slowly over the course of the entire semester, rendering some of their concepts unfeasible and/or inadequate. The team was therefore unable to achieve their overall project goal and their concepts failed to meet several of their product requirements. |

> [Finally] we were able to have a meeting with all of them… that discussion was productive in figuring out what we should be doing." [Team 4; Interview 4].

Due to early struggles with defining their project goals, over the duration of the course, Team 4 increased their level of engagement with their project stakeholders, particularly their end-users. They realized that better communication strategies were needed to resolve discrepancies between stakeholder needs and began conducting group interviews so that their end-users had opportunities to discuss their conflicting viewpoints. Toward the end of the semester, the benefits of Team 4's extensive stakeholder engagement were apparent: Team 4 delivered a successful prototype to its sponsor and the team recognized that deeply understanding all their stakeholders' various needs was a key to their success.

By comparison, Team 1 felt that they started the semester with a well-defined project. As they described:

> "A lot of [the user requirements] was easy because [our sponsor] had a very clear idea of what exactly she wanted. She was pretty solid on her input of requirements, so it was pretty easy to just add specs onto that." [Team 1; Interview 1].

Since they viewed their project as already well-defined, Team 1 decreased their engagement with stakeholders as the semester progressed. However, during later design stages, Team 1's sponsor changed their mind about the features that they wanted Team 1 to incorporate into their solution:

> "There were some [features] that [our sponsors] kind of thought of late, that they wanted to add…they didn't really tell us about [the features] until way into the designing process…and we were less able to accommodate them." [Team 1; Interview 4].

As a result, Team 1 was forced to make several last-minute changes to their product requirements and engineering specifications and failed to develop a successful prototype. Team 1 felt that they could have potentially avoided these late-stage design challenges if they had possessed more comprehensive knowledge about their project from the beginning of the semester. As they described:

> "From the perspective of us interacting with [our sponsor], we were more sort of trying to get our bearings, so we weren't able to ask them a lot of the more in-depth questions… as we got towards like the DR2 area… [our sponsor] thought of a lot of [these other features] and that was when we more were able to give them better feedback and what we were experiencing in design, asking them questions." [Team 1; Interview 4].

In other words, Team 1 interpreted their stakeholder-related design challenges as mainly resulting from a lack of domain knowledge at the beginning of the semester, which prevented team members asking appropriate questions to accurately define their design problem.

### Teams 5 & 7: engagement factor—team's perspectives on stakeholder engagement

Teams 5 and 7 had similar projects and engaged with stakeholders in substantially different ways over the semester. Both teams developed a medical device, were sponsored by clinicians, and had opportunities to engage with diverse stakeholders (including end-users). Team 7 engaged with stakeholders extensively throughout the semester, interviewing clinicians, experts, and other stakeholders to make design decisions. They also consistently described the importance of engaging stakeholders to inform design work:

> "Stakeholders should be a huge source of information in the design process. It is important that the needs and wants of the stakeholders are clearly understood so that the designers can evaluate, work, and change with [stakeholders'] ideas in mind." [Team 7; Post-semester survey].

Team 7's perceptions and approaches to stakeholder engagement most closely aligned with human-centered design among the teams in our study.

In contrast, Team 5 spent most of the semester with the perception that its project sponsor was the only stakeholder whose opinion was important. In their words:

> "I wouldn't say mostly, I would say that all of our user requirements came from [our sponsors]." [Team 5; Interview 1].

Not until they were required to engage with end-users by the mentoring course professor did Team 5 interview stakeholders other than the sponsor. When they did engage with end-users, Team 5 received considerable feedback and was required to generate new concepts in order to develop a product that met the requirements of the end-users. These late-stage interactions led Team 5 to change how they understood the importance of stakeholder engagement:

> "If I were to redo this [project], I would have just right off the bat generated a couple prototypes and put them in people's hands and said, 'Look at this. What are your initial thoughts?' Because we got some really cool feedback once we started actually… testing." [Team 5; Interview 4].

## Teams 2 & 6: engagement factor—information applicability

Teams 2 and 6 had similar projects and used very similar design processes with respect to stakeholder interactions. Both teams engaged with stakeholders during early stages of their projects (particularly problem definition, requirements elicitation, and defining engineering specifications). During these interactions, however, both teams encountered difficulties with the information obtained. Team 2 found that information gathered from domestic clinicians conflicted with the information gathered from clinicians in a West African setting:

> "That was interesting because all the [West African] doctors were valuing some things differently than the American professionals and doctors. I remember [Sponsor] didn't think [feature] was very important at all, but then every time we did this survey [with West African doctors], it was like the top of the list." [Team 2; Interview 1].

By comparison, Team 6 believed that the information gathered from stakeholders was not directly relevant to the project and could not be used:

> "They gave us a lot of…ideas that we looked into but most of them…would be way too expensive." [Team 6; Interview 2].

Both teams ultimately reduced their interactions with stakeholders as the semester progressed, turning instead to information sources such as academic literature, global health websites, and benchmarking. For example, as described by Team 2:

> "We've been able to use the literature really, really well. We found super detailed information… like [Non-Profit] detailing the exact number, or like, a bunch of a things like durability, safety… Nurses in [West African country] have not been helpful much." [Team 2; Interview 2].

Similarly, Team 6 also discussed how they engaged fewer stakeholders than anticipated to develop their user requirements.

> "Talking to our project sponsors… [and] looking at their articles [were] the main [sources of our user requirements]… we didn't really talk to any nurses or biomedical technicians because… as we understood what we're looking for more, we narrowed down to the more key, uh, I guess projected information sources that we utilized." [Team 6; Interview 2].

In other words, Team 6 engaged fewer stakeholders than anticipated because they felt that stakeholders such as nurses or biomedical technicians were unlikely to provide useful information, compared to other information sources such as academic literature.

### Team 3: engagement factor—stakeholders' ability to provide quantitative information

Team 3's project involved reducing the manufacturing costs for a consumer product and was sponsored by an international durable goods company. Team 3 viewed their sponsor as the primary beneficiary of their project, and thus also their most important source of information. Their initial interactions with the sponsor were promising, allowing them to define a clear overall goal for the project (cost reduction) and to define several product requirements.

> "Most of our requirements came directly from [our sponsor]. The main goal of our project was to reduce cost." [Team 3; Interview 1].

However, as the semester progressed, the need for additional quantitative, project-specific information increased, and Team 3 perceived that their interactions with their sponsors were less meaningful.

> "[Our sponsor] didn't really… [give] any numbers… [it] was kind of hard to try and pull specifications out of thin air when we were given next to nothing to go on." [Team 3; Interview 4].

Team 3 consequently consulted other information sources to define their design problem and identify possible solutions, which ultimately led the team to make inaccurate assumptions about their project. For example:

> "We were under the impression that the costs were more similar to like an American manufacturing process… but apparently out in [East Asian country where the product is manufactured]… the cost of [manufacturing process] was like ten, fifteen percent of the overall cost of the [product], whereas we were under the assumption that it was more like sixty percent." [Team 3; Interview 4].

Due to these inaccurate assumptions, Team 3 developed a solution that met the minimum cost reduction goals of their sponsor but fell well short of the team's personal cost reduction goals.

## Discussion

We identified several similarities and differences in how participating capstone teams in this study engaged stakeholders to inform their design projects. These similarities and differences revealed factors that seemed to drive teams toward or away from stakeholder engagement. For example, teams with rigidly defined projects, strongly opinionated key stakeholders (particularly sponsors), and negative initial interactions with stakeholders tended to decrease their engagement with stakeholders as the semester progressed. In contrast, teams with projects that required further definition, that had multiple and diverse stakeholders, and who had more human-centered design philosophies maintained or increased their engagement with stakeholders over the semester. These findings demonstrate the effect that project definition, type and quantity of stakeholders, and student perceptions can have on the level of stakeholder engagement performed by design teams.

For Teams 1 and 4, the level of perceived finality of their design problem impacted their stakeholder engagement approaches. Team 4, who perceived their design problem as ill-defined and thus was in need of more problem definition, engaged stakeholders in more depth than Team 1, who perceived their design problem as well-defined. Literature has described how engineering student designers may treat design tasks as well-defined, straightforward problems that they prematurely attempt to solve (Atman et al., 2007; Crismond & Adams, 2012). The approach of Team 1 aligns with this literature of how engineering students approach design tasks, which impacted the extent to which they sought additional information from stakeholders. By comparison, Team 4's stakeholders did not initially agree on their problem definition. While this situation frustrated Team 4, it also highlighted for the team that their design problem was ill-defined. Our findings further show that because Team 4 perceived their design problem as ill-defined, they were motivated to engage more deeply with their stakeholders. Prior studies have demonstrated that engineering student designers strongly associate stakeholder engagement activities with problem definition (Loweth, Daly, Hortop, et al., 2021; Rao et al., 2021). Thus, it seems likely that other engineering student teams, beyond Team 4, might also respond to clearly ill-defined design problems by engaging more with stakeholders. The case of Team 4 also suggests that project factors, such as the inclusion of core stakeholders with clearly conflicting viewpoints, can highlight the ill-defined nature of design problems for engineering students, and may counter engineering students' tendencies to approach their design problems as well-defined.

Our comparison of Teams 5 and 7 illustrated that design teams' perceptions of the value of stakeholder engagement can affect their level of stakeholder engagement. While both teams had opportunities to engage diverse stakeholders from the outset of their projects, only Team 7 engaged stakeholders consistently throughout the semester, in part because they highly valued diverse stakeholder perspectives. Team 5, by comparison, initially relied solely on its project sponsor for relevant information and largely ignored other stakeholders. Prior work has shown that engineering students' perceptions of stakeholder engagement may vary substantially from a technology-centric design approach with minimal appreciation for the role of stakeholders to a human-centered approach that emphasizes empathic design methods (Zoltowski et al., 2012). Loweth et al. (2021, 2019), studying another capstone context, also found that engineering student designers' perceptions of the value of stakeholder engagement can impact their engagement approaches. Our findings align with this prior work. Furthermore, given Team 5's struggles to create an appropriate solution that met their user's needs, our findings also uniquely show how possessing more techno-centric or limited views on stakeholder engagement can negatively impact engineering students' design processes. In addition, we also found that Team 5's perceptions of stakeholder engagement changed over the semester. When Team 5 finally interacted with its end-users, they began to take a more human-centered approach. These findings mirror prior observations from Loweth et al. (2019), who similarly found that meeting with end-users could in some cases drastically and positively affect capstone design teams' perceptions of the value of stakeholder engagement activities. By the end of the semester, both Teams 5 and 7 had a fuller appreciation for stakeholder engagement during design.

Analysis of Teams 2 and 6 compared how perceptions of information applicability impacted how engagement with stakeholders. Both teams responded to perceived challenges they experienced gathering what they deemed as *relevant* information from stakeholders by reducing their engagement with stakeholders over the course of the semester and turning to other sources of information instead. Receiving information that is not straightforward to apply is a common part of stakeholder engagement for several reasons. Stakeholders may lack the design or engineering knowledge to provide specific feedback on design deliverables (Østergaard et al., 2018; Sanders & Stappers, 2008). Stakeholders may also struggle to describe tacit or abstract knowledge in concrete terms (Crabtree et al., 2012; Sutcliffe & Sawyer, 2013). Prior studies have shown that engineering student designers may be frustrated by challenges with information applicability in stakeholder engagement (Mohedas et al., 2014a, 2020; Sugar, 2001). Our findings show that these challenges can lead engineering students to interact with fewer stakeholders than they originally intended.

Team 3 was highly dependent upon their sponsor from the beginning of the semester as a source of information, in part due to their foreign project context. Our findings highlight how frustrations related to translating stakeholder information into quantitative specifications led teams to decrease their engagement with stakeholders. Previous work by Mohedas et al. (2014a) described how engineering students struggled to solicit information from stakeholders that they felt was directly relevant to their user requirements. Team 3's frustrations may also reflect struggles with synthesizing stakeholder data. Difficulty with information processing has been noted in prior literature where student designers tend to directly transfer information gathered to design decisions (such as when Team 3's sponsor provided them with the goal of cost reduction) and ignore information that requires further synthesis and analysis to inform decision making (Alexandersson & Limberg, 2003; Limberg, 1999; Wilson, 1999). Loweth, Daly, Sienko et al. (2020 found that engineering student designers struggled to translate feedback from stakeholders into user requirements and specifications and consequently supplemented their user requirements and specifications with their own assumptions. Our findings align with these prior observations of engineering student designers. They also demonstrate how challenges with information gathering and synthesis can negatively impact engineering students' stakeholder engagement approaches and overall design processes.

## Limitations

This study focused on collecting an extensive amount of data on a small number of student design teams. While the outcomes are not generalizable, the goal was transferability, meaning that the rich detail collected and the findings reported function as a model for other researchers to apply and translate into their own contexts (Malterud, 2001). Therefore, application of these findings to other contexts will depend upon the degree of similarity of the new context to that described in this study. While details regarding the characteristics of students included in our sample were collected (e.g. gender, major, and prior design course experience), other factors such as race, ethnicity, and extracurricular design experience were not. These details should be taken into consideration when transferring the results to other contexts.

This study used retrospective self-reporting as the major source of data for analysis which can be biased by inaccurate recall and biased reporting. Attempts were made to minimize these effects by conducting interviews immediately after each major milestone in the project (minimizing the length of time students were asked to recall), using group interviews, and focusing discussion on design decisions made (preventing students from attempting to provide the 'right' answers with respect to stakeholder engagement).

One important aspect not studied within this research was the effect of stakeholder interaction on final design quality or the quality of design decisions made. While we recognize this to be a critically important topic, the large number of confounding factors and small number of design teams in our study precluded judgments on whether stakeholder interaction had a significant effect on design quality.

Lastly, participants were interviewed within a group setting and our analytic approach focused on teams' overall experiences. One limitation of this study approach was that we did not know the individual students' experiences with stakeholder engagement during design prior to taking the capstone design course. Individual team members having a natural or developed talent for engaging with stakeholders may have influenced the overall teams' perceptions regarding the usefulness of stakeholder engagement when making design decisions. To define a baseline of comparison, studies could first attempt to understand these students' characteristics at the beginning of the course. Another limitation of this study approach was that we did not collect data on internal dynamics among team members, for instance related to race or gender, that could have influenced our findings.

## Educational implications

The results provide insight into how design projects (within an academic setting) might be formulated to better encourage human-centered design processes and increase stakeholder engagement by design teams. Courses encouraging significant stakeholder interaction (e.g. capstone design courses) could begin with clear explanations of the best approaches for eliciting critical information and feedback from stakeholders and building constructive relationships between designers and stakeholders (Dieter & Schmidt, 2012; Loweth, Daly, Hortop et al., 2020, 2021; Strickland, 2001).

Instructors of courses with significant stakeholder interaction should implement projects that emphasize the ill-defined nature of design problems. As shown with Teams 1 and 4, this goal may be accomplished through projects involving multiple core stakeholders with conflicting perspectives. The navigation of these conflicting perspectives can lead engineering students to spend more time defining their design problems and engaging with stakeholders. Instructors might also seek to support engineering students' "framing agency," which Svihla et al. define as "the agency to make decisions that are consequential to framing [i.e., understanding, defining, and bounding] design problems" (2021, p. 96). In our study, Team 1 seemed to exhibit low framing agency compared to their sponsor, which seemed to be a significant reason that the team perceived their design problem as well-defined despite their sponsor's repeated changes. Team 4, who took deliberate actions to better define their design problem, seemed to exhibit moderate to high framing agency. Instructors can support students' framing agency by introducing strategies that students may use to frame and re-frame design problems (e.g., as described by (Dorst, 2015; Kim et al., 2020; Murray et al., 2019)) and explore differences in stakeholder perspectives (e.g., as described by Lehoux et al., 2011; Loweth, Daly, Hortop et al., 2020).

Instructors should also encourage early and frequent interactions with stakeholders. In addition to being a recommended practice for stakeholder engagement (Agid & Chin, 2019; Loweth, Daly, Hortop, et al., 2021), these early interactions can also positively impact engineering students' perceptions of the value of stakeholder engagement. For example, Team 5 in this study might have developed a more positive view of stakeholder engagement earlier had they been required to or had the opportunity to engage with users in their initial design stages. To facilitate students in engaging stakeholders early, instructors might introduce tools such as stakeholder maps and other methods that support designers in identifying a diverse range of stakeholders. This goal might also be accomplished by scoping design projects with multiple key stakeholders that are highly engaged within the project, as described in Loweth et al. (2019).

Lastly, instructors should support students in identifying information goals for their stakeholder meetings and utilizing stakeholder information. Our findings indicate that struggles related to gathering and synthesizing stakeholder data can lead engineering students to decrease their engagements with stakeholders in ways that may lead to less positive design outcomes. Instructors may address these struggles by supporting students in clarifying needed design information—i.e., "known unknowns" or information that the design team knows that they are missing (Sutcliffe & Sawyer, 2013)—and identifying appropriate methods for gathering this design information. In particular, students would benefit from instruction in using low-fidelity prototypes to probe stakeholder perspectives and gather specific data that can inform engineering specifications (Deininger et al., 2017; Luck, 2018). Instructors may also support students by introducing methods for processing stakeholder data. Traditional tools for translating stakeholder data into user requirements and specifications include Kano modeling and Quality Function Deployment (Dieter & Schmidt, 2012; Ullman, 2010), but engineering students would also likely benefit from instruction in more qualitative methods for analyzing stakeholder data as well.

## Conclusion

Our study explored how engineering student designers in a capstone design course engaged stakeholders to inform their design decisions. We compiled narratives of how each of the seven teams in our study engaged stakeholders throughout the semester and analyzed these narratives to identify key factors that seemed to affect how participants engaged stakeholders in practice. Factors that led teams to engage more with stakeholders through the semester included: an ill-defined initial problem involving several conflicting perspectives, the ready availability of multiple and diverse stakeholders, and team perspectives that favored stakeholder engagement. Factors that led teams to engage less with stakeholders included: a rigidly defined initial problem, highly opinionated key stakeholders, and challenges interpreting or applying stakeholder information. These factors highlight specific challenges that engineering student designers may encounter during stakeholder engagement, as well as contextual factors related to team projects that ultimately affect students' approaches. Design instructors can use our findings to develop pedagogy that supports engineering student designers in adopting effective stakeholder engagement practices. Additionally, instructors can use our findings to create curricular design projects that are conducive to positive stakeholder engagement experiences and thus provide effective environments for students to practice more human-centered design approaches.

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**Competing interests** The authors have no non-financial competing interests to declare that are relevant to the content of this article.

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