Student Designers' Interactions with Users in Capstone Design Projects: A Comparison Across Teams

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Abstract

Users play an important role in engineering design projects, from providing the basis for user requirements to defining how designs will be used in practice. However, student designers often struggle when interacting with users to elicit requirements or solicit design feedback. This study explored how three capstone design teams perceived the role of user interactions in their design projects, as well as the way each team approached their user interactions. One team viewed their project primarily as a technical challenge that did not require user input and consequently never met with their user. Another team saw user interactions as important mainly for informing user requirements and met with their user at the start of the semester to iterate on these requirements. However, this did not meet with their user again until after their prototype was completed. The third team viewed user interactions as important both for informing requirements and for soliciting design feedback. This team met with their user regularly while developing their prototype but were not always intentional in how they planned or conducted their interactions. These three perspectives point to specific gaps in student knowledge related to user interactions that future design pedagogy might target to help students elicit requirements and solicit design feedback from users more effectively.

1. Introduction

Those who have a relationship of use with design solutions – defined as "users" – play an important role in engineering design projects [1]. The use of any technology is defined by those who use that technology [2]–[7], and user acceptance strongly influences which technologies become widely adopted [7]–[10]. Designers may interact with users for a number of reasons, such as to elicit user requirements or to solicit feedback on solution concepts [2], [7], [11]–[13]. However, one challenge that designers often encounter when eliciting requirements or soliciting feedback is that individual users have their own unique perspectives that often change over time or conflict with those of other similar users [2], [6], [7], [14]–[16]. As such, understanding and balancing the perspectives of different users can be a difficult task, but one that has substantial implications for the success of a given design project.

Engineering students in particular may encounter difficulties when interacting with users to elicit requirements or solicit design feedback. For instance, previous studies have described cases where engineering students struggled to manage the subjective aspects of user responses [17], [18], understand and adopt user language [18], [19], explore user experiences [20], and leverage the full potential of prototypes to uncover user requirements [21]. On the other hand, direct interactions with users can help engineering students refine their understanding of their design problem and keep user requirements in mind when generating solution concepts [7], [22], [23]. In general, these previous studies have focused primarily on the outcomes of student designer interactions with users. Few studies thus far have explored in depth how student designers perceive the role of user interactions in their design projects and how students' perceptions may in turn influence their approaches to these interactions. This study explored how student design teams perceived of and interacted with users as part of a capstone design course.

2. Background

Previous research has shown that user interactions can help engineering students better understand user requirements and generate design concepts that meet these requirements. For instance, interactions with users helped students recognize user capabilities and preferences and reference these aspects of the user when generating design concepts [7], [22], [23]. Frequent interactions with users may also provide an opportunity for students to receive feedback on their ideas and make sure that that their design deliverables are aligned with the user's true needs [12], [22], [24]. However, previous studies have focused primarily on the outcomes rather than the content of students' interactions with users; as such, there may be a knowledge gap related to the process that students use to elicit requirements or solicit feedback during user interactions. In other words, previous studies have often described what students learned about their users through their interactions, but not how students learned this new information.

Other research, focusing on situations where students did not interact with users, indicates why user interactions in and of themselves may be beneficial for student design outcomes. In lieu of collecting data from users, student designers may instead extract generalized information about users from third-party research or rely on their own personal perspectives and preferences to fill in the gaps in their knowledge [7], [23], [25]. This tendency may be most problematic when students have not themselves experienced the problems encountered by their user; students without this experiential connection may spend inadequate time scoping their design problem before trying to develop technical solutions [26]. Thus, students who do not interact with users might be more inclined to make inaccurate assumptions about user requirements, ultimately leading them to develop solutions that do not meet the user's true needs [27].

While interactions with users may be beneficial for student designers, simply providing access to users does not guarantee that student designers will take the initiative to interact with their users if given the choice or that students' approaches to these interactions will be successful. For instance, previous studies of capstone design courses have shown that engineering students may struggle with managing the subjective aspects of user responses during interactions [17], [18]. In addition, these students may not have fully conceptualized the value and broad uses of design tools, such as prototypes, for interacting with users to elicit requirements or solicit feedback [21]. Other studies show that student designers may struggle to adopt user language during interactions [18], [28], or may act in such a way as to discourage users from sharing their experiences in depth [20]. These studies suggest that while user interactions may help student designers better understand explicitly observable aspects of their users, these students may also struggle to dive deeper into their user's experiences and fully leverage these experiences when making design decisions. As such, frequent interactions with users are not guaranteed to help students align their solution concepts with user needs; students must also be able to employ effective strategies for eliciting requirements and soliciting design feedback [24], [29].

Student designers' approaches to and motivations for interacting with users are likely influenced by how they perceive the value of user interactions for informing design decisions. Depending upon previous design experiences, student perspectives on the value of these interactions may vary substantially: some students may view user interactions as unnecessary for developing appropriate solutions while others may view these interactions as essential [30], [31]. However, previous research on student designers has not explored in depth the link between different student perspectives on user interactions and the different ways that students approach these interactions. On one hand, many studies have described the process and impact of different student approaches to user interactions in experimental settings [12], [23], [25], [31]. For example, van Rijn et al. [23] explored how different sources of information, including user interactions, impacted the alignment of team design deliverables with user needs. However, access to users and different sources of information was carefully controlled as part of the study and it is unclear how each team would have approached user interactions in a non-experimental setting. Meanwhile, other studies have explored how students interpret their user interactions in design courses [7], [17], [18], [21], [24] or co-curricular projects [20], [22], [32]. For instance, Hess & Fila [22] describe how students utilized information from user interactions to develop and evaluate solution concepts during team meetings and design reviews. However, this study did not collect data on the content of these interactions. This study sought to address this research gap by comparing transcripts of student interactions with users in a capstone course setting to student interpretations of these experiences. By addressing this research gap, we hope to inform future design pedagogy related to user interactions in capstone projects.

3. Methods

3.1 Research questions

This study aimed to draw a connection between the perspectives of student designers regarding the role of user interactions in capstone design projects and the approach that these students took to user interactions as a result. The research questions that guided this study were:

1. **What are the different ways that student design teams perceive the role of user interactions in their capstone design projects?**
2. **Based on these different perspectives, how do student design teams approach interactions with their users as part of their projects?**

By studying the different ways that teams perceived the role of user interactions in their projects and the ways that teams approached user interactions based on their perceptions, we hoped to identify 1) factors that led to frequent and positive interactions with users, which should be encouraged, and 2) factors that dissuaded students from interacting with users or taking full advantage of these interactions, which might be addressed in future capstone design settings.

3.2 Participants

Data were collected from three design teams enrolled in a single-semester senior-level capstone design course at a large Midwestern university. All three teams were developing assistive devices for young adults with physical disabilities, and a specific individual was assigned to each team at the beginning of the semester to serve as the project's user. All three projects topics had been addressed in a prior capstone design course by other students; each team thus had access to the former student design team's design reports and prototypes. Each team was composed of three to five undergraduate students majoring in mechanical engineering, all of whom had at least three semesters of previous experience with project-based design courses as well as one to three years of experience working on design projects in co-curricular and internship settings. Most of the participants were also enrolled in additional project-based design courses concurrent with their capstone course. Roughly half of the participants identified as Caucasian, with the other half identifying as Asian and one student identifying as Latino. This breakdown was reflected evenly across the three teams. The majority of students on each team identified as male, with a single student on each team identifying as female.

3.3 Data collection

The data discussed in this paper were collected as part of a larger study exploring how capstone design teams interacted with project stakeholders, of which "users" are a specific sub-group. In the case of the three teams in this paper, the term "stakeholder" refers exclusively to the team's user and other associated individuals who knew the user personally.

This study collected two main types of data: semi-structured interviews conducted by the first author with each team and recordings of meetings that each team completed with their user and associated individuals. The goal of this data collection was to develop thick descriptions of each team's perspectives on and approaches to user interactions that might facilitate comparison of perspectives and approaches across teams and the identification of perspectives or approaches that may be transferrable to other student design contexts [33], [34].

First, each team completed three different semi-structured interviews, hereafter referred to as "researcher interviews." The first interview occurred at the beginning of the semester to discuss each individual participant's prior knowledge about interacting with stakeholders in design projects. The second interview occurred after each team had met with either their user or an associated individual for the first time to gather initial impressions about stakeholder interactions in the context of each team's project. The third interview occurred at the end of the semester after teams had met with their stakeholders for the final time and focused on the general approach that each team adopted in interacting with their user and associated individuals as part of their project. These three sets of interviews resulted in over ten hours of audio data. The interview data presented in this paper focus primarily on team responses related to their users.

In addition, each team submitted recordings of the meetings that they conducted with their stakeholders, hereafter referred to as "stakeholder meetings." These meetings represented an additional eight hours of audio data. While there are many ways that a design team might interact with stakeholders in design projects ("interview" was the term most commonly used by the research team while collecting data), "meetings" was the term used most consistently across teams to describe their interactions with both users and with associated individuals. Recordings of stakeholder meetings and researcher interviews were transcribed to facilitate data analysis.

Protocols for researcher interviews were developed, following methodology for rigorous qualitative research, to assure comparability across participant responses [34], [35]. Each protocol was organized around a series of open-ended questions designed to elicit stories and examples, as well as probing questions to dive deeper into participant responses. Examples of relevant questions are presented in Table 1. While preparing for each round of interviews, the research team iterated on their questions by piloting each protocol with undergraduate students who had previous design experiences comparable to study participants. The semi-structured interview format also facilitated the use of spontaneous probes to explore unique responses in greater depth and better understand each participant's individual perspective.

Table 1. Examples of relevant questions asked during interviews

Interview	Questions
Second interview	• What is the goal of the project? • Who is your sponsor? • What stakeholders would be impacted by the outcomes of your project? • What information did you discover from the interview? (*this question was asked for each meeting that the team had conducted up to this point*)
Third interview	• How do you feel that conducting interviews impacted your design project? • How did the interviews you conducted impact your understanding of the design problem/design requirements and specifications/generation, development, or selection of design solutions? (*asked separately*) • How well do you think your final solution for this course addressed your client's needs? (*not all teams in the broader study had explicit users, so the term "client" was chosen instead; all three teams described in this paper interpreted "client" as their user*) • What challenges did you encounter in this course relating to conducting interviews? • How did the capstone course environment, teaching, structures, etc. impact your ability/motivation to conduct interviews? (*asked separately*)

3.4 Data analysis

Data analysis was completed in two parts. First, transcripts from stakeholder meetings were analyzed by two coders to identify the specific ways that each team interacted with their users and associated individuals. Similar interactions were then thematically grouped into specific behaviors, such as building relationships and involving users in design decisions, to allow for comparison across teams [36]–[38]. Next, the two coders reviewed the transcripts of researcher interviews to determine how each team interpreted their interactions with users and associated individuals. These interpretations included each team's rationale for interacting with their user, their preparation for these interactions, and perceived outcomes from these interactions. The three cases presented below synthesize the researcher interview and stakeholder meeting data for each team into coherent narratives that represent each team's overall perspectives and approach.

4. Findings

Findings are presented below in three subsections, with each subsection providing a case description of a single student design team. These cases describe each team's perspective on and interpretations of user interactions within the context of their design project, as well as the approach each team took to interactions with their user or associated individuals.

4.1 Team A: No user interactions

Team A viewed the project purely in terms of building a prototype that met the user requirements established during a previous semester by a different student design team and thus saw no reason to meet with their user.

Team A's project had two main stakeholders: their user and an associated individual (hereafter referred to as the "volunteer") who worked with the user at the local non-profit sponsoring the project. Design deliverables from the former design team included a video recording of the user interacting with the non-profit's current device, a set of user requirements, and a prototype based on these requirements. Team A began the semester by meeting with the volunteer from the local non-profit. Based on this meeting, the team felt that they had a clear idea about the prototype iterations that needed to be completed, namely:

> *[W]e need to create back support, a quick-release mechanism, some form of… [hand] support… As well as… something that provides the medical aides support for the patient.*

One reason why Team A focused primarily on iterations to the former design team's prototype was because they felt that their design problem and user requirements had already been fully specified by this former team. As Team A explained:

> *[T]he previous team had already established the needs. I guess what we did… was more go to [the volunteer] and [ask], 'Okay, this is what the other team did based off what [the user] needed. Is there anything that you need us to change?' Basically her response was, 'No, the other team didn't finish this. Finish this, and then ...' We raised a few questions about altering some of the requirements and specifications, like adding more attachments, but the [volunteer] ultimately said no so we just stuck to the original.*

In other words, Team A felt that the volunteer was satisfied with the current set of requirements and assumed that the user was likely satisfied as well. Team A thus felt that they needed no further input from their user before proceeding to prototype iterations.

Analysis of Team A's meetings with the volunteer from the local non-profit revealed a further reason why this team may have had some hesitation about meeting with their user: Team A felt unsure what the purpose of this interaction should be. This hesitation arose during discussions of whether to show the current CAD iteration of the prototype to the user:

Team A:	*…[We] wanted to discuss if there's a chance that we could meet with [User] and her parents?*
Volunteer:	*Yeah. I had emailed you back, I think.*
Team A:	*We thought it might not be worth it if we don't have an actual prototype to bring with us to the meeting, because we do have to drive like two hours…*
Volunteer:	*Okay… it's not two hours.*
Team A:	*Like an hour?*
Volunteer:	*… We could find somewhere to meet halfway or something. I guess that's up to you guys, if you wanted to meet her sooner, or if you wanted to wait until you were working on [the prototype] to show them... that's your call, if that makes sense?*
Team A:	*Oh. Yeah. One of the other teams in our session... met with their [user] who's also a child with [a disability]. They met during the design phase, which has passed already…they…show[ed] different prototypes that they came up with… and he chose which one he liked. We don't have that.*

This exchange started with Team A citing travel distance as a substantial obstacle to interacting with their user. However, the volunteer pushed back that the travel distance was not that far and "*…we could find somewhere to meet halfway…*" In response, Team A discussed the deeper reason behind their hesitation to meet with their user: they did not yet have a physical prototype to demonstrate and without this prototype felt that interacting with the user might not provide new and useful information. While Team A was aware of how other students (in this case, Team C described below) had interacted with their users, they were unsure how these interactions applied to their case since the design problem and user requirements already seemed defined.

In lieu of meeting with the user, Team A made assumptions about the user's capabilities and the way that the user would interact with their prototype. For instance, when demonstrating a CAD rendering of their final design to the volunteer, Team A described their design decisions thus:

Team A:	*The purpose of this meeting is to update you with our design decisions. We're moving forward with what we came up with. First, here is a slideshow of a computer model… [of] what we are envisioning for the back rest. We basically would take what the past team has done, except that we wanted to change the connection by using a bicycle clamp…*
Volunteer:	*Yeah that's fine ... Whatever you ...*
Team A:	*Yeah… We wanted to change it because, when we tried to use the prototype they made, it was kind of hard for us.*
Volunteer:	*So is that instead of the ...*
Team A:	*The pushpin button. Yeah.*
Volunteer:	*So is it like ... Sorry I probably sound dumb, but is it… you know how scooters, when you lift the top up, and it's that clamp thing?*
Team A:	*Yeah. Yeah. Exactly.*
Volunteer:	*Gotcha.*
Team A:	*We thought this would be easier for all of us to understand and work with.*

Specifically, Team A assumed that because their design change from a button to a clamp made the design easier for them to use, this change would also likely benefit the user. However, the team moved forward with this design change without verifying that it would have the intended effect for their user. The process exhibited in this excerpt allowed Team A to finalize their design by the mid-point of the semester and proceed to developing a high-fidelity prototype. At the end of the semester, Team A felt that their final design was successful and met all their user requirements, although they would have liked the opportunity to test the design with their user.

4.2 Team B: Limited user interactions

Team B viewed user interactions as useful primarily for iterating on user requirements. As such, this team only met with their user to elicit these requirements and validate their final design.

Team B also had two main stakeholders: the user and an associated individual. In this case, the associated individual was an engineering professor at the university who knew the user personally and was sponsoring the project. As with Team A, design deliverables from the previous semester included user requirements and a prototype, although in this case Team B also had access to a video recording of the user interacting with the former design team's prototype.

Team B began their semester by first meeting with the professor sponsoring the project. Based on this meeting, Team B felt that they had a clear idea about the specific task that their project needed to accomplish, specifically enhancing their user's mobility:

> *[Our project is] designed specifically for [User] and she can [perform this task] slightly, but… she needs help [doing it all the way]. We're designing something that could [help]. There was a project last year already, and they had a fully functioning product, but we wanna work on improving that product. So, make it simpler, take out a few steps, and then make it lightweight and durable.*

Unlike Team A, Team B emphasized that the current prototype was functional but did not fully meet the goals of the project relative to assisting the user. As such, Team B felt that substantial changes should to be made to the current design to make it simpler and easier to use.

Team B met once with their user at the beginning of the semester to iterate on their user requirements. The primary goal of this interaction was to learn more about the usability issues of the former design team's prototype as they related to the user's physical capabilities:

Team B:	*…If you can remember, when you were using the prototype, what were the biggest challenges that you thought when using [it] last semester?*
User:	*Maybe carrying it… I don't know. I don't remember how much it like weighed or anything… I'd have to use it again to see.*
Team B:	*For sure. In regards to carrying it, currently it weighs 10 pounds. Is it the weight that's the biggest challenge or is it also the size or ...?*
User:	*Not the weight but how I... I'm wondering how I would carry it around.*
Team B:	*Okay. So, basically how it attaches to your walker and things like that.*
User:	*Yeah, 'cause I have a scooter… how would that work with the scooter?*

In the above exchange, Team B identified a potential requirement that their device should be light-weight and interpreted this requirement as "less than 10 pounds." Pushback from the user ("…*not the weight but…*") led the team to specify "attachment to the walker" as an additional key requirement. Team B then used the requirements generated during this meeting to guide their design decisions. They did not meet with the user again until the end of the semester to verify that their design worked as predicted.

Team B felt that their project was a success because they built a functional prototype that met many of the requirements specified during their user meeting. As one team member expressed:

> *I think we did a pretty good job. We made a lot of incremental changes, and [User] seemed to really like them. We have a clear vision for the future… there's definitely more iteration that can be done on this prototype. I think we hit most of the user requirements that we wanted, and we did have a functioning prototype, but at the end [encountered] some unforeseen consequences, which are not unusual [for] design challenges such as*

these. They affected the end result, so we had to troubleshoot a lot, and the fact that we were still able to create a functioning prototype with all the troubleshooting really shows that we were efficient in our process of decision making and manufacturing…

In other words, Team B listed user approval, hitting requirements, and technical functionality as their key criteria for defining success. While the team experienced unforeseen consequences, they felt that these challenges were typical of complex engineering projects and concluded that their ability to overcome these challenges proved the efficiency of their decision-making process.

One interesting caveat was that, when asked about user requirements that had been more difficult to meet, Team B cited "easier to use" and "customized to their user." As the team described:

I think just making it easier to use, because of the limited face time we had with [User]. If we had more time, and more interviews that we could conduct with her, we could make [the prototype] a lot more customized. Based off of the requirements we had, we have a good end product, but consulting with [User] more in the future would help create a more customized end-result. For example, our cylinder right now does the job, but I think it's long so if we cut that short a couple inches… little things like that to make it even better in the next iteration.

Team B felt that many of the current issues with their prototype, such as the length of the cylinder, seemed relatively minor and could be easily fixed in the future. However, the team also admitted that the sum of these minor issues was that their prototype was not as "customized" to their user as they would have liked, impacting the prototype's practical usability. Despite these usability issues, Team B felt that they had produced a successful design that met their user's needs and provided a solid foundation for future design iterations.

4.3 Team C: Frequent user interactions

Team C viewed user interactions as important both for informing user requirements and for soliciting design feedback. As such, this team met with their user consistently throughout the project and involved their user as an active design participant.

Like Teams A and B, Team C inherited a set of user requirements and a physical prototype from the previous semester. In addition to their user, Team C interacted with associated individuals that included the user's parent, physical therapist, and teachers. Team C generally interacted with all these individuals at the same time to collect information from many different perspectives.

Team C initially thought about their project in terms of the technical challenge to be solved. However, after meeting with their user and stakeholders for the first time, the team realized that:

[His parent's] primary focus isn't necessarily that this has to perform [especially well]…it just needs to engage [User] with his peers. That's why they were so pleased with the progress that they saw last semester… It didn't serve the functions that they really wanted. It didn't do what [User] wanted, as far as control… but it served their function of getting [User] engaged and participating in the class.

By meeting with the user and associated individuals, Team C began to recognize the broader goals that their user had for the design project, as well as the ways that these goals contrasted with the goals that Team C had initially assumed. As the team later elaborated:

> *I'm not sure that it was surprising retrospectively, but at the time I thought it was quite remarkable that [the parent] came out and said that the primary focus for us is getting [User] to participate, rather than getting the device to do the job. We were going in with the attitude of we need to hit XYZ, and then we're going to need to move an object from point A to point B at X velocity… whereas their focus is much less can you build something that works, so much as it is can you help [User]? Which retrospectively, duh, but at the time it was remarkable for me to hear that from the parent.*

In other words, the perspectives of the user and associated individuals during this initial meeting were surprising enough for Team C that they prompted reflection about how engineering's traditional focus on the more technical aspects of solution concepts may have initially caused the team to overlook their user's true needs. This realization substantially impacted how Team C perceived the role of future user interactions in their design project.

From this point onwards, Team C consistently involved their user in making design decisions and, when possible, tried to explain the project in terms that the user could understand. For instance, the team opened their second user meeting by explaining that:

> *Team C:* *…Since we last met with you, [User], we talked to the group that was working on the device last time… We've put together a couple of our preliminary ideas, got their feedback, and put together design requirements from the feedback you gave us. Based on that, we built a couple of [functional] prototypes we brought to show you today… They're the rough sketch of what we're thinking. We want to get your feedback on them, and then we're going to take one of those, based on what we think's going to be the best… and try to build that full-scale for you.*

In this excerpt, Team C described the value of their user's earlier contributions, the work that the team had done in the meantime, and the specific feedback that the team was looking for in the current meeting. These explanations helped the user actively participant in design decisions throughout the project, although most of these decisions pertained to concept development as demonstrated above. Team C did not consult with their user about the translation of data from their meetings into user requirements and in retrospect viewed this as a missed opportunity.

At the end of the semester, Team C cited two key aspects of their approach that they felt helped them develop a successful prototype. First, Team C met with their user as often as possible, given the user's availability and distance from the team. As one team member expressed:

> *I think ours was a heavily user centric project because it was being catered to [User]. Without interviews our product wouldn't have been remotely successful. Our design was somewhat iterative. We would go there, we would look at some things and we would go back and redesign based on what we found. Without as many interviews as we had, even*

if we had one less interview… our chances of success would drop massively… I don't think you have a project… [unless you] form a close relationship with the kid.

In other words, Team C emphasized that their project could not exist independently of their user. Since the team was creating a heavily customized design, they adopted an iterative approach to make sure that each design decision they made was well suited to their user's capabilities and preferences. Another team member elaborated on this point, noting that:

Let's say we were given an identical object and [told], "Make a machine just independent of [User]." I don't think we would have been as successful as we were. None of us are disabled. None of us can fully comprehend the daily challenges he goes through. I don't even think any of us still quite do, but we have a better understanding of some of them. That was really important to this project, because it is a child with a disability.

This quote highlights how the user's disability also helped Team C realize that there was much about the user and the user's experience that they could only find out through direct interactions. Rather than making assumptions about what the user might need, Team C endeavored whenever possible to answer their questions about the design by consulting the user.

In addition, Team C credited the relationship that they established with their user for contributing to their team's success. This relationship developed through the more casual exchanges that formed a substantial portion of each meeting. Team C found that they developed a sense of mutual trust with the user that soon led to the user driving parts of their meetings:

There became an element of trust once we met him for a bit… We were very fortunate that [User]… [is]an exceptional person and he has a very positive attitude and is a very outgoing person… It caused a lot of excitement for him, and he ended up being able to drive at some points during the meeting just by asking questions and talking about what he wanted to know. Or even just totally deviating from what the topic was and inviting [his sibling]… to play outside with him to demo the product. All the while we're there gathering data, looking at it and figuring out what's going on and what we need to do to make it better. At the same time it's him enjoying himself which is very gratifying to see from our perspective…if the kid is happy then our semester is successful.

Thus, Team C realized that letting their user occasionally lead meetings could provide new and serendipitous opportunities to collect additional data. Team C felt comfortable letting the user deviate from their initial plan because they recognized that the resulting interactions could be valuable as well. This flexibility was a direct outcome of the mutual trust that the team developed with their user by devoting time to relationship-building during each meeting.

However, even though Team C created a prototype that they felt aligned well with their user's capabilities, they also recognized that they did not meet many of the user requirements that they had set out to achieve at the start of the semester. As one team member pointed out:

[The prototype] meets the two most important things. One it's safe, two it makes the kid happy. It met the requirement his [parent] laid out which was increased engagement. We

don't meet a lot of our specifications as far as direction [control], power, weight, perhaps installation of the device… and yet we can still call it a success because the kid is happy.

In other words, Team C ultimately felt that their prototype was a success because it was safe, it made the user happy, and it increased the user's engagement with friends and family. Even though the prototype did not meet some of the team's requirements related to weight or fine control of the device, Team C felt that these issues did not substantially affect the immediate satisfaction of their user and might be improved through future iterations.

5. Discussion

5.1 Team perspectives on user interactions and corresponding approaches

The three cases presented in this study show three distinct perspectives related to the role of user interactions in capstone design projects, as well as three approaches to interacting with the user that are likely related to these perspectives. These three cases are summarized in Table 2.

Table 2. Summary of teams' perspectives and approaches

Case	Perspective on user interactions	Approach to user interactions
Team A	Requirements and design problem defined in advance so no further need to consult user	Team never met with their user
Team B	User interactions are useful primarily for iterating on user requirements	Team met with user once to learn about their physical capabilities and translated these capabilities into requirements
Team C	User interactions are important both for informing user requirements and for soliciting design feedback	Team met with user frequently throughout the semester and involved their user in the project as an active design participant

The team perspectives on user interactions described in Table 2 resemble previous descriptions of student perspectives on human-centered design [30]. The primary contribution of this study was to elaborate on these previous findings with detailed cases and to draw a link between student perspectives on and approaches to user interactions in a capstone course context.

Team A recognized that their user was an important source of user requirements. However, they felt that these requirements had already been determined in advance and thus saw no further need to consult their user. The perspective of this team could be categorized as "Technology-centered," or "the focus of the design is on the technology and solving the technical problem, not on the 'others' or humans. The approach lack[ed] both an understanding of the users and an appreciation of the users' knowledge, experience, and perspective" [30, p. 39]. Based on this perspective, Team A focused solely on the technical aspects of the project, finalizing their design by the midpoint of the semester and spending the rest of their time on fabrication.

Team B saw user interactions as important primarily for iterating on user requirements. When Team B wanted feedback on their solution concepts, they consulted their professor-sponsor, who they felt could make informed decisions on the user's behalf. As such, the perspective of this team could be categorized as "Keeping the Users' Needs in Mind," or "…keeping the users' needs and how [the] design will be used in mind while designing… gathering information about the users primarily from higher level stakeholders or experts versus the users directly. Integrating that information with aspects of technical feasibility and viability is done to the extent that disciplinary knowledge allows" [30, p. 39]. Based on this perspective, Team B interacted with their user at the beginning of the semester to learn more about their physical capabilities and designed a solution with these physical capabilities in mind. However, Team B only met with their user again at the end of the semester to verify that they had met their functional goals and did not explore in depth how their user would interact with the prototype.

Team C saw user interactions as important for both informing user requirements and soliciting design feedback. The team viewed their user as an important participant in the design project and developed a deep personal connection with the user. The perspective of this team could thus be categorized as "Empathic Design," or "basing [the] design on knowledge gained through a connection with end users, not on preconceived ideas and assumptions. A very broad understanding of stakeholders is developed beyond the scope of the project by interacting with users informally and in social situations" [30, p. 39]. Based on this perspective, Team C felt that frequent meetings with their user were vital to the success of their project and endeavored to meet with their user as much as possible. The team used these meetings to iterate on their design concepts and their understanding of the design problem throughout the project, adopting a flexible approach that allowed for new and surprising information to continuously emerge. The team consistently involved the user in design decision-making in the hope of keeping their design activities in close alignment with the user's true needs.

5.2 Similarities and differences across team perspectives

Each team in this study represented a unique perspective on user interactions that corresponded to a unique approach. However, the thick case descriptions presented in this study facilitate identification of similarities and differences across team perspectives that may also help explain similarities and differences in the ways that teams approached their user interactions.

First, Teams A and B both viewed their project primarily in terms of designing *for* their user, treating the project as a service that the team was performing [6]. In other words, both teams saw their user as a beneficiary of the project, but not necessarily someone who could provide useful design feedback. Meanwhile, Team C viewed their project primarily in terms of designing *with* their user and frequently involved their user in design decision-making [6]. This difference in perspective between Teams A and B and Team C may help explain why Teams A and B met with their user rarely, if at all, while Team C met with their user consistently throughout the semester. Team C felt that user interactions substantially contributed to their project's success, while Team B emphasized their efficient decision-making process despite a lack of user input.

Both designing *for* and designing *with* users can have advantages and disadvantages, and both perspectives can be valuable for design projects. For instance, designing *for* users may be more efficient in a time constrained project such as a single-semester capstone course [7], [39]. Users also might not be well equipped to provide feedback on technical functionality or assist with data analysis [40]. Lack of user input, however, may lead student designers to make inaccurate assumptions about user needs and requirements [7], [23], [25].

On the other hand, designing *with* users can enable the user to provide direct and targeted feedback about the appropriateness of design concepts or even contribute their own design ideas [6], [15], [41], [42]. However, designing *with* users may require advanced knowledge about cross-disciplinary communication and information gathering [43]–[45] that few student designers have had the opportunity to develop [18], [21], [28]. For example, Team A felt that they would only obtain useful information from their user if they could leverage a functional prototype for the user to interact with and seemed unaware of other useful ways that they might interact with their user. Based on these advantages and disadvantages, each team would ideally have incorporated aspects of both designing *for* and designing *with* users in their perspectives on user interactions. A more balanced perspective might have helped all three teams plan the timing, frequency and settings of their user interactions more intentionally in relation to their project.

Second, Teams A and B both described the success of their project mainly in terms of meeting their user requirements. By comparison, Team C described the success of their project in terms of the close relationship that they developed with their user and their user's satisfaction with their prototype. Team A did not meet with their user. However, this difference in perspective between Teams B and C may help explain why Team B's user interaction focused primarily on developing user requirements based on their user's physical capabilities, while Team C's user interactions focused primarily on soliciting design feedback and building relationships.

Interestingly, Teams B and C both started their semester evaluating success in terms of meeting user requirements. As Team C pointed out, this initial focus on requirements may have related to engineering's traditional emphasis on technical troubleshooting and measuring observable phenomena [46]–[48]. In Team B's case, this orientation towards observable requirements may have led the team to concentrate their data collection around their user's physical capabilities rather than their user's potential goals or priorities. This approach to data collection may explain why Team B's prototype was not fully customized to their user's use context and thus still hard to use even though the team met most of the user requirements that they had identified [18], [49].

Meanwhile, Team C adjusted their definition of project success to reflect the "engagement-first" perspective of their user and associated individuals and placed less emphasis on their user requirements. At the end of the semester, their user expressed high satisfaction with the team's prototype and Team C interpreted this satisfaction to mean that their design effectively met their user's needs. However, Team C also failed to meet many of their user requirements related to weight of the device and fine control during use. While this poor performance on requirements did not seem to negatively impact the user's satisfaction, it does raise questions about how well Team C's design met their user's explicit and latent needs [12], [13]. At the very least, Team C struggled to synthesize their knowledge of the user into relevant requirements that they could then use to evaluate the suitability of their design from an engineering perspective [18], [49].

5.3 Limitations

This study has two main limitations. First, team approaches to user interactions may be very context dependent. For instance, the short timeframe of the single-semester capstone course may have caused students to interact with their users less than they might have otherwise. However, this capstone context likely did not affect each team's initial perspectives about the role of user interactions in their projects, and the broad patterns demonstrated by each team's approach could be transferrable to other student design contexts. Second, this study did not analyze in depth the personal factors that led each team to adopt different initial perspectives on user interactions. While teams were roughly homogenous in terms of previous design coursework, team composition, and project goals, there may have been other co-curricular experiences or personal factors that influenced how each team perceived the role of user interactions in their project.

5.4 Implications for Design Education

The findings from this study have two main implications for future design pedagogy. First, capstone design students need a broader conceptual framework that might help them understand the role of user interactions within their projects and conduct these interactions effectively. This framework should include 1) best practices for user interactions [50]–[52], 2) an overview of the different ways to involve users in design projects [2], [6], [7], [40], [41], [52], and 3) descriptions of different situations where relevant user interactions might occur [4], [5], [7], [41]. Much of the research into these different areas already exists. What is needed is a framework that links these different components together into a cohesive whole to inform student practice. All three teams in this study would have benefitted from such a framework. For instance, Team A might have recognized and sought out other feedback that they needed from the user that had not already been covered the previous semester. Team B might have devised additional ways to solicit relevant feedback from their user despite a tight timeframe. Team C might have been more intentional in soliciting feedback on their design concepts and translating this feedback into iterations on their user requirements. There are several different ways that capstone course instructors might effectively teach this user interaction framework, such as through case analysis and discussion [7], [53], audio records of interviews, or role-playing exercises [54]–[56].

Second, capstone design students would benefit from critical reflection on how they naturally break down and conceptualize engineering design projects. This reflexivity is often encouraged in more qualitative fields [35], [57] but is generally lacking in engineering [6], [58], [59]. The case of Team C suggests that greater reflexivity might help engineering students account for their user's wants and specific context when identifying requirements and developing solution concepts. However, capstone design instructors should encourage students to identify not only their potential biases as engineers, but also the unique ways that students might leverage their engineering identities when developing requirements and solution concepts. For instance, while involving users in design decision-making is important for keeping solution concepts aligned with user needs, engineers are also uniquely equipped to analyze the data they are receiving from their users and translate these data into unique insights about potentially latent needs or requirements [13], [40]. Encouraging reflexive behavior might thus help capstone students both acknowledge how their engineering perspectives may impact their user interactions and also leverage these perspectives intentionally when planning and interpreting these interactions.

6. Conclusion

This study identified different ways that capstone design students working on assistive devices for specific users perceived the role of user interactions in their design projects, as well as the ways that each team approached these interactions. Teams A and B viewed their project as a service that they were performing for their user and evaluated the success of their projects primarily in terms of meeting their user requirements. Team A never met with their user because they felt their requirements were specified in advance. Team B met with their user once to iterate on their user requirements and again at the end of the semester to evaluate their prototype. While Team B met many of their user requirements, their prototype still was not fully customized to their user's use context and thus somewhat difficult to use. By comparison, Team C developed a close relationship with their user and frequently involved their user in design decision-making. While Team C felt that their prototype effectively addressed their user's unique challenges, they also acknowledged that they did not meet many of their user requirements such as weight and fine control of the device. To help capstone design students better understand the role of user interactions in design projects and conduct these interactions more effectively, capstone instructors might provide a broader conceptual framework that links together best practices for user interactions, different ways to involve users in design projects, and descriptions of different situations where relevant user interactions might occur. Capstone instructors might also encourage their students to reflect on how their perspectives as engineers may impact their user interactions and suggest ways for students to leverage these perspectives more intentionally.

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