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Students' perceptions of the value of stakeholder engagement during engineering design

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Abstract

Background: Human-centered design approaches promote and facilitate comprehensive understanding of stakeholders to inform design decisions. Successful engagement with stakeholders is critical to favorable design outcomes and requires skillful information gathering and synthesizing processes, which present unique challenges to student designers.

Purpose/Hypothesis: Our study sought to answer the following research question: What factors influence design teams' perceptions of the value of stakeholder engagement during design decision-making?

Design/Method: During a capstone design experience, we conducted four semistructured group interviews with seven capstone undergraduate student design teams and collected their design reports. We analyzed the data across teams to identify factors that influenced teams' perceptions of the value of stakeholder engagement.

Results: Teams perceived stakeholder specific interactions to be more useful when they prespecified a goal for the interaction, interacted with stakeholders who had specific subject matter expertise, or ceded control of the decision-making process to stakeholders. Students perceived interactions to be less useful when information gathered varied across stakeholders or when information was not directly applicable to the design decision at hand.

Conclusions: The factors this study identified that influenced students' perceptions of the usefulness of stakeholder interactions elucidate specific challenges students encounter when engaging with stakeholders. Students could benefit from pedagogical structures that assist them throughout design-related engagement with stakeholders and when applying the information gathered through engagements with stakeholders to design decision-making.

KEYWORDS
design, human-centered design, information gathering, stakeholder engagement

1 | INTRODUCTION

A host of modern design philosophies, including human-centered design, user-centered design, empathic design, and participatory design, focus designers' attention on the individuals who will be affected by a designed artifact. When guided by people-focused design processes, designers often spend significant time and resources defining the wants and

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needs of stakeholders, involving stakeholders throughout the design process, and seeking to understand stakeholders in a holistic manner (Zhang & Dong, 2009). Extensive stakeholder engagement is critical to decisions designers must make throughout their design processes, including refining design objectives to reflect what the "real" needs are; developing solution ideas that are appropriate for the context; and obtaining deep knowledge of how future products, services, or systems may be used (Steen, De Koning, & Pikaart, 2004; Walters, 2005). Various forms of interaction can be leveraged during stakeholder engagement, including interviews, focus groups, surveys, observations, participatory design workshops, and cocreative partnerships (Grudin & Grinter, 1995).

While stakeholder engagement is central to many design philosophies, there are a limited number of studies that examine how best practices in stakeholder engagement are learned and implemented by student designers (Kim & Wilemon, 2002; Steen et al., 2004). Further, literature describing best practices for engaging with stakeholders is not concentrated in a single field, and few curriculum materials exist to support engineers in successfully engaging stakeholders. Based on the findings from studies that have investigated how students engage with stakeholders during design processes, it is evident that students struggle with knowing how to develop appropriate goals for and effectively execute engagements with stakeholders. (Mohedas, Daly, & Sienko, 2014a; Scott, 2008; Sugar, 2001). They also tend to be unsuccessful when applying the information gathered to design decisions and reduce engagement with stakeholders as the semester progresses.

However, existing studies have not focused on specific ways that students successfully and unsuccessfully engage with stakeholders in their design work. Further, a particular focus on stakeholder interviews is needed due to the ubiquity of stakeholder interviewing across design approaches. To facilitate integration of successful stakeholder engagement into engineering education, it is important to understand how students currently approach and perceive stakeholder engagement. Our study investigated what factors affected students' perceptions of the value of their stakeholder interactions during their design work. These perceptions of value likely impact the quality of information yielded, the extent to which stakeholder data are integrated into design decisions, and students' likelihood to engage stakeholders in their future design work.

2 | BACKGROUND

2.1 | Stakeholder engagement during design

A design stakeholder is any individual who may be affected by the eventual designed artifact (e.g., end-users, customers, clients), the process of its creation (e.g., manufacturers, designers, investors), or its distribution and end of life (e.g., purchasers, retailers, distributors) (Ballejos & Montagna, 2008; Donaldson & Preston, 1995; Freeman, 2010; Hertzum, 2014; Hull, Jackson, & Dick, 2005; Sharp, Finkelstein, & Galal, 1999). This inclusive definition of a stakeholder is common in design philosophies that emphasize human impacts of an artifact during its life cycle.

Many design approaches emphasize stakeholder engagement including empathic design (Leonard & Rayport, 1997), participatory design (Sanoff, 2007; Schuler & Namioka, 1993), human-centered design (Schmid & Collis, 1999; Zhang & Dong, 2009), user-centered design (Bayazit, 2004; Gulliksen et al., 2003), inclusive design (Clarkson, Coleman, Keates, & Lebbon, 2003; Newell & Gregor, 2000), cocreative design (Sanders & Stappers, 2008), and design ethnography (Salvador, Bell, & Anderson, 1999; Wasson, 2000). While these approaches differ in focus on particular stakeholders and the methods by which they engage with stakeholders, they all emphasize the key role of people in design decision-making, including that stakeholders should be understood holistically and involved throughout the process; that artifacts should be designed to emphasize usefulness, usability, and desirability by stakeholders; and that end-users as well as other stakeholders who may be affected by the designed artifact should be considered (Gulliksen et al., 2003; IDEO.org, 2015; Norman, 1988; Salvador et al., 1999; Vredenburg, Mao, Smith, & Carey, 2002; Zhang & Dong, 2009). Design approaches that emphasize stakeholder engagement have been shown to improve the quality of the designed artifact, reduce costly features that do not meet the needs of stakeholders, improve uptake of the final product, and reduce training necessary for end-users to begin to use a product (Damodaran, 1996; Gould, Boies, Levy, Richards, & Schoonard, 1987; He & King, 2008; Karat, 1994; Kujala, 2003; Maguire, 2001; Vredenburg et al., 2002). Industry surveys have shown that design approaches that include stakeholder engagement are becoming more common in practice settings (Vredenburg et al., 2002).

Prior research has elucidated the importance of engagement with stakeholders during the earliest phases of design (e.g., problem definition and requirements elicitation), showing that early engagement leads to product requirements that better address the needs of stakeholders as well as the context of their deployment (Anderson & Crocca, 1993;

Neale & Corkindale, 1998). The importance of stakeholder engagement in other phases of product development, such as concept generation, concept evaluation, and usability assessment, has also been demonstrated; studies have shown that stakeholder engagement during these phases leads to the generation of more novel concepts, products with higher probabilities of success, and more ergonomic and user-friendly products (Lilien, Morrison, Searls, Sonnack, & Hippel, 2002; Urban & von Hippel, 1988; von Hippel, 1977). In addition to common engagement methods (e.g., surveys, focus groups, interviews), newer methodologies have been leveraged that seek to gather deeper, more meaningful information from stakeholders, including ethnographic inquiry (Grudin & Grinter, 1995; Salvador et al., 1999), paired comparisons, role-playing, and protocol analysis (Davis, 1992; Dym, Little, & Orwin, 2013; Goguen & Linde, 1993).

2.2 | Information gathering, synthesis, and application during design

When successfully employing people-focused design approaches, designers must prepare effective, nonbiased interview protocols (Agarwal & Tanniru, 1990), overcome communication and disciplinary boundaries to gather relevant information (Van Buren & Cook, 1998), synthesize often-divergent perspectives across stakeholders (Wang & Zeng, 2009), and apply information gathered to design decision-making. Best practices for designers when conducting stakeholder interviews include developing rapport with the stakeholders (Dieter & Schmidt, 2012; Strickland, 2001; Tsai, Mojdehbakhsh, & Rayadurgam, 1997), encouraging stakeholders to synthesize and analyze their prior knowledge (Leifer, Lee, & Durgee, 1994; Rosenthal & Capper, 2006), and verifying stakeholders' conclusions and interpretations (Firesmith, 2003; Nuseibeh & Easterbrook, 2000). Additionally, effective interviews with stakeholders tend to be semistructured, thus requiring interviewers to be flexible and opportunistic to elicit the stakeholders' "real" wants and needs (Agarwal & Tanniru, 1990; Luck, 2007; Nguyen, Carroll, & Swatman, 2000; Strickland, 2001). Finally, and especially important, is that designers aim to develop empathy for stakeholders so that when designers make design decisions, they consider a deep understanding of the motivations and experiences of their stakeholders (Blomberg & Burrell, 2003; Brown, 2008; Gray, Yilmaz, Daly, Seifert, & Gonzalez, 2015; IDEO.org, 2015). Empathy development requires an interview setting and questions that allow the stakeholder to be comfortable as well as an interviewer who conveys deep interest in the stakeholder's experiences through good listening, supportive responses, and appropriate follow-up questions.

After useful information is gathered, designers must then analyze stakeholder data. There are a variety of techniques for analyzing stakeholder data, including the development of personas, theme identification, card sorting, user stories, and consumer journey maps (Creswell, 2013; Guenther, 2006; Holtzblatt, Burns Wendell, & Wood, 2004). These techniques represent a particularly open-ended and resource-intensive form of *information use*, where information is gathered, synthesized, and then applied to a problem (Ingwersen & Jarvelin, 2005). In contrast, *information transfer* occurs when information is treated as an object and can be directly applied to a problem without prior analysis or synthesis. During design, information use is a cognitively demanding task during which designers must often navigate conflicting information across different stakeholders or contradictions between stakeholder interviews and other information sources (Wilson, 1999). Arriving at a design decision when contradicting information is encountered can be challenging, and repercussions of the decision may not be revealed until much later in the design process.

2.3 | Student engagement with stakeholders

Engineering courses have increasingly included design processes that emphasize stakeholders (Klatsky, 1998; Oehlberg, Leighton, & Agogino, 2012). However, prior research has shown that students do not always interact with stakeholders successfully (Mohedas, Daly, & Sienko, 2015; Scott, 2008; Sugar, 2001). For example, in design course projects, students have been shown to struggle navigating ambiguous information, analyzing qualitative data, and identifying what stakeholder information is important to their design decisions (Mohedas et al., 2014a, 2014b, 2014c). Other studies have highlighted challenges students have encountered during stakeholder interviews, such as ensuring that critical topics are covered during the interview; asking appropriate questions; uncovering how stakeholders think or feel about certain topics; and obtaining information about social, political, and cultural factors that may affect design decisions (Burnay, Jureta, & Faulkner, 2014; Donoghue, 2010; Goguen & Linde, 1993; Wetherbe, 1991).

Research has explored some parameters that may impact students' decisions to engage stakeholders and their approaches to stakeholder engagement. For example, students may not have the appropriate skillset to gather, analyze, and apply stakeholder data. Stakeholder engagement often results in a large amount of data (Beyer & Holtzblatt, 1998;

Sachidanandam & Gill, 2008), and studies have shown that during a design course students may shift away from a human-centered view of design if the complexity of gathering and synthesizing multiple diverse perspectives from stakeholders during decision-making proves too burdensome (Mohedas et al., 2014a; Scott, 2008). In one study, although most student designers acknowledged the benefits of incorporating stakeholders' input into front-end design processes, they encountered obstacles while doing so and often interacted with stakeholders in a superficial manner (Mohedas et al., 2014a, 2014c). Another study of novices and experts performing a design task found that novices spent less time than experts in gathering information (Atman et al., 2007). In a study of capstone design students, although most students understood the value and benefit of information gathering and synthesis, they typically gathered less information than originally planned during design projects (Mohedas et al., 2014b). Minimal and/or superficial engagement with stakeholders prevents student designers from fully leveraging the extensive benefits of stakeholder engagement and, therefore, does not allow them to develop the necessary skills to engage with stakeholders in the future.

Even when students are able to gather useful information from stakeholders, they may fail to apply it in purposeful ways, for example, trivial product changes (e.g., the addition of a user-manual vs. significant changes to a product to make it more user-friendly) (Sugar, 2001). Novices have also been shown not to assess the quality and/or validity of the information obtained prior to applying it to their problem (Alexandersson & Limberg, 2003; Hultgren & Limberg, 2003; Limberg, 1999; McGregor & Streitenberger, 1998). These challenges with stakeholder engagement may be, in part, a consequence of engineering students' limited experiences with qualitative data, which is traditionally the type of data gathered during interviewing, or a viewpoint that qualitative data are not valuable.

Beyond a lack of stakeholder engagement skills, the time constraints of design work could also prevent students from effective stakeholder engagement as time constraints have been shown to hinder students and professionals in developing creative design ideas (Amabile et al., 2002; Tolbert & Daly, 2013). Additionally, course requirements and assessments or company incentives can influence the level and quality of stakeholder engagement.

Further, students may not value stakeholder engagement during design or may consider stakeholder engagement as secondary to a main focus on performance and functionality; similar findings have shown that students prioritize the technical elements over understanding their customers (Dannels, 2000). Some students have a technology-centered perspective on design and a lack of appreciation of the role of people in design decisions (Zoltowski, Oakes, & Cardella, 2012), and student designers have been shown to hold a narrow view of stakeholders during their design processes, focusing on performance characteristics and neglecting end-user concerns (Coso, 2014). These studies demonstrate that requiring stakeholder engagement, and even providing foundational skill development opportunities, might not be wholly effective in supporting students in applying people-focused approaches; their perceptions of how useful stakeholder engagement is during their design processes must also be considered.

3 | RESEARCH DESIGN

Our study asked the following research question:

What factors influence design teams' perceptions of the value of stakeholder engagement during design decision-making?

We sought to explore the influences 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 student perceptions of the value of stakeholder interactions and how they approached these interactions. We traced the progress and decision-making of seven undergraduate design teams over one semester of a capstone design course. This approach allowed us to understand how each team engaged with stakeholders during all design phases, and after aggregating all reported instances of design decisions and stakeholder engagements, to identify factors affecting students' perceived value of the interactions (Case & Light, 2011; Creswell, 2013; Flyvbjerg, 2011; Gerring, 2005; Patton, 1990). The study was approved by the Institutional Review Board of the University of Michigan, and all study participants provided written informed consent.

3.1 | Qualitative research approach and theoretical foundation

Our study applied a qualitative approach to understand students' perceptions of the value of engaging with stakeholders. A qualitative approach allowed us to gather rich descriptions and allowed the emergence of important factors.

The study was grounded in an interpretivist epistemology (Lincoln & Guba, 1985) as our primary objective was to assess students' perceived value of stakeholder engagement rather than measure a "true value" of stakeholder engagement during design processes. While the value of stakeholder data has been confirmed in a host of contexts, it is unclear from the literature the extent to which student designers value stakeholder engagement when designing and how their behaviors during stakeholder engagement change as a function of the value they perceive.

Our research team took specific steps to reduce or confront potential biases. Three of the four authors have extensive experience with the use of design ethnography, a design methodology that emphasizes stakeholder engagement throughout the design process. To account for a positive bias toward stakeholder engagement, our team focused on students' perceptions (rather than what value they were actually deriving from stakeholder engagement). Additionally, we structured our group interview protocols (as discussed below) on students' decision-making practices, which reduced the likelihood that students answered interview questions with the intention of meeting the preconceptions of the researcher (e.g., that stakeholder engagement was a key resource during design). Consensus coding was also used to assess the presence of biases. In particular, we chose a second coder who had no prior experience with design and stakeholder engagement to serve as a check throughout the data analysis process to avoid potential impacts of biases.

3.2 | Participants and context

The study participants included 28 undergraduate students across seven teams enrolled in a capstone design course in mechanical engineering. Teams were enrolled in the study if three of the four team members volunteered to participate. Requiring that at least three members participate increased the likelihood that we would capture the full extent of stakeholder engagement performed during the semester as well as potentially differing opinions on stakeholder engagement among team members. A breakdown of the characteristics of the students who participated in the study is shown in Table 1. The header "previous design courses" refers to the number of design courses students took prior to the capstone design course. Compared to the College of Engineering overall, our study enrolled fewer female students than are represented in the student population (18% in our study vs. 28% in the College of Engineering) (*Facts & Figures*, 2019). Due to the low number of biomedical engineering students in our sample, we cannot make separate comments about the representative nature of our sample within each disciple individually. Race/ethnicity data were not collected.

The seven teams that participated in the study were working on a range of design project types (e.g., laboratory equipment, medical devices, consumer products) and with a range of sponsor types (e.g., professors, companies, medical doctors). All students attended the same weekly lectures. Three professors mentored the teams (Teams 1 and 4; Teams 5, 7, 2, and 6; Team 3) and assigned grades based on four design reviews (detailed below). None of the professor mentors were also design team sponsors. The professor mentor for Teams 1 and 4 was also part of the research team. The projects (described in a general sense throughout the text to maintain participant anonymity) and sponsors are listed in Table 2. By recruiting design teams with a diverse array of projects, sponsors, and professor mentors, the findings may be more easily transferred to other design class contexts, particularly capstone design courses.

The capstone design course had four design review milestones: Design Review 1 (DR1) required the teams to define their design problem, list design requirements, and develop engineering specifications; Design Review 2 (DR2) required them to generate diverse concepts, down-select to a top concept, and develop a mock-up; Design Review 3 (DR3)

TABLE 1 Characteristics of students participating in study

Characteristic	Frequency
Sex	
Male	23
Female	5
Academic major	
Mechanical engineering	26
Biomedical engineering	2
Previous design courses	
Three	23
Four	5

TABLE 2 Description of design teams participating in study

Team	Project description	Project sponsor
Team 1	Design a piece of laboratory equipment for a biomedical engineering research laboratory	Biomedical engineering professor
Team 2	Design a consumer medical device for use by pregnant women in a low-income country	Mechanical engineering professor and physicians from low-income country
Team 3	Design a consumer product	Durable goods company
Team 4	Design a piece of laboratory equipment for a mechanical engineering research laboratory	Mechanical engineering professor
Team 5	Design a consumer product for pregnant women	Physician from high-income country
Team 6	Design a diagnostic device for community healthcare workers in a low-income country	Nongovernmental organization
Team 7	Design a medical simulator for use in a low-income country	Mechanical engineering professor and physicians from low-income country

required them to perform an engineering analysis on one or more components of their design and use the results to refine the final design; and Design Review 4 (DR4) required them to develop and preliminarily assess a functional prototype.

While this study focused on stakeholder engagement during design, the capstone course was not explicitly designed to emphasize stakeholder engagement (e.g., there were no specific learning outcomes focused on stakeholder engagement). While not a primary focus of the course, students attended lectures on interviewing stakeholders during design (particularly during requirements development) and engaging with stakeholders was encouraged early on in the course by the course instructors. Teams also may have been encouraged to incorporate stakeholder engagement into their design processes by course instructors when they reached a difficult decision point. However, design teams could choose the extent to which they engaged with stakeholders throughout the duration of their design projects. Further, the number of accessible stakeholders varied by project; some design projects had a small number of potential stakeholders, for example, the stakeholders for Teams 1 and 4 who were university research groups, while other design projects had a large number of potential stakeholders, for example, Teams 2, 3, and 5, who were designing medical devices or consumer products for easily accessible stakeholders.

3.3 | Data collection

Primary data were collected during four semistructured group interviews. Design team group interviews lasted between 40 and 70 min. Group interview sessions were conducted in the week following each design review to coincide with the four course milestones. Group interviews had the same overall structure for each team during the study. The group interview protocol structure was based on design as a decision-making process: we asked teams to explain the decisions made, how they were made, and the information sources that contributed to the decisions (Hatamura, 2006). An additional design team (not included in our analysis because they were sponsored by the lead author) was recruited to pilot test all interview protocols to enable changes to be made (for clarity and to ensure all relevant topics were covered) prior to participant team interviews.

Example questions for each group interview session conducted are included in Table 3. The interview protocol for each team was modified from the foundational structure based on the information teams provided in their design reports. Specifically, prior to the group interviews, we read design team reports and identified the key design decisions reported by the student team since the previous group interview. Group interview questions were then customized to better understand the information gathered by the team to make design decisions. By reading team reports in advance, we ensured that major design decisions were unlikely to be missed, and the semistructured nature of the group interviews provided flexibility to cover the design decisions not evident in the reports during interviews. Prior research showed that design students claimed that stakeholder interactions had a significant impact on their design outcomes even when analysis of design reports and decisions pointed to minimal incorporation of stakeholder feedback (Sugar, 2001). Given this potential bias, our interview protocol focused on asking questions regarding design decisions rather than on stakeholder

TABLE 3 Example questions from protocols developed for design team group interviews

Interview session	Example questions
Interview Session 1 Interview focus: Problem definition, requirements elicitation, and engineering specifications	• What is the goal of your project? • Tell me in general how you developed product requirements. ○ Follow-up questions: Where did they come from? What information did you use? Where did this information come from? • Do you think the requirements are accurate? ○ Follow-up questions: Will satisfying those requirements result in a successful design? • Let us pick a specific user requirement and talk about it in detail. How did this user requirement arise? How was it developed? What information did you use to generate the requirement? • What do you still need to learn or information you need to collect/gather for your design project? In general and/or in specific.
Interview Session 2 Interview focus: Concept generation, down-selection, and mock-up development	• First, let us 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? ○ Follow-up questions: Was new information involved in the change? Where did this new information come from? Was this change important? • 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 Session 3 Interview focus: Engineering analysis, prototyping and validation plans	• Did your team make any changes to product requirements or engineering specifications? ○ Follow-up questions: Was new information involved in the change? Where did this new information come from? Was this change important? • How did you choose the components or systems to perform the engineering analysis? • What information did you gather to make this decision? From what sources? • How has your design changed from the end of the second design review? ○ Follow-up questions: What were the major changes? Why did you make the changes?
Interview Session 4 Interview focus: Final prototype and validation, overview of design experience	• Do you think your final design was successful? Why or why not? ○ Follow-up questions: What aspects make it successful? What part of the design process do you think contributed most to the success? • What design tools did your team find most useful during the semester? ○ Follow-up questions: What decisions did they specifically help you make? • How would you proceed if you were to keep working on the project long-term?

engagement directly. Students were prompted to discuss all the information sources that contributed to a design decision (without direct requests to name stakeholders involved). Only after stakeholder interaction was mentioned as a source of information during design decision-making did we ask follow-up questions specific to stakeholder interaction.

3.4 | Data analysis

Transcripts were first analyzed to identify each segment in which a stakeholder interaction was mentioned by students. Stakeholders were defined as an individual who may impact or be affected by the eventual designed artifact. Experts (who were not end-users) and course instructors were not included as stakeholders. We considered each instance of engagement with a stakeholder described by participants and its associated design decisions as an analysis unit. For example, if one of our interview questions led the participants to discuss how they engaged with their end-user to review an updated version of a prototype, the transcript section describing how they prepared, conducted, assessed, and used information for that interaction would represent a single unit of analysis. Student interactions with stakeholders took several forms, including e-mails, phone calls, interviews, and group interviews. However, engagement with stakeholders most often took the form of an interview. Within our data set, 110 instances of stakeholder interactions were mentioned by student design teams. Two coders analyzed all transcripts in the data set. Discrepancies in coding were discussed, and consensus was reached for all discrepancies.

Once all units of analysis were isolated, we first coded the transcripts for whether the students perceived the stakeholder interaction to be useful. We created a dichotomous categorization scheme where each interaction was classified as "useful" or "not useful" based on how students described it. According to students, the usefulness of an interaction was determined based on if it "helped them" in some way, for example, making decisions, understanding the problem, identifying tools to perform analysis, or choosing between concepts. In many cases, students were explicit if they felt the interaction helped them in their design work, saying, for example, "We had a lab tour, and that helped us … understand what we were doing," as well as if they felt the interaction did not help them, saying, for example, "We talked to Dr. [ ], it wasn't the most fruitful conversation but we did talk to her and I guess that we thought that she had more … expertise in this area." In other cases, the "useful" code was applied because students pointed directly to the connection between an interaction and making a design decision, for example, "[The discussion] changed our design a little bit in the sense that we needed to have … a broader range of capability." Some instances were less clear, and in these cases, we used the larger transcript (beyond just their description of the single interaction) and the design report in combination to classify the interaction as useful or not. Again, multiple coders judged usefulness, and discrepancies were resolved through discussion by the coders and larger research team.

After determining the usefulness of each of the 110 interactions, we considered three prominent aspects of stakeholder engagement in design from literature that we thought might relate to perceived usefulness by students: (a) design phase in which the teams were engaged, (b) type of stakeholder with whom the team interacted, and (c) communication form (Agarwal & Tanniru, 1990; Dieter & Schmidt, 2012; Firesmith, 2003; Leifer et al., 1994; Luck, 2007; Nguyen et al., 2000; Strickland, 2001; Tsai et al., 1997). The design phase codes were applied primarily based on the general phases that coincided with the structure of the capstone design course. However, design teams also returned to specific phases later in their design processes (e.g., returning to problem definition after using a prototype to realize shortcomings in prior decisions). Stakeholder type codes were based on the most common stakeholders that students encountered: sponsor (the principal stakeholder sponsoring their design project and to whom they present their final product), end-users, expert end-users (end-users who also have additional expertise in the field; e.g., a physician who would use their final product but also performs research in the field the students are working in), and other (e.g., service technicians, purchasers, distributors). Communication form was coded based on typical methods of communication that students used to engage with their stakeholders. The codes for each of these factors are shown in Table 4.

For further investigation into what factors might relate to students' perceptions of usefulness, we analyzed the data using an inductive lens, guided by recommended practices (Creswell, 2013). Specifically, we read and analyzed stakeholder interactions students deemed useful and not useful, and identified themes among their reasons for describing the interaction as useful or not. We developed five additional factors based on themes that emerged in this inductive review. We present and define these discovered factors related to perceived usefulness in the Findings section.

4 | FINDINGS

Among the seven teams' 110 interactions with stakeholders throughout the semester, 61 were categorized as useful and 49 as not useful as perceived by the students. Using these 110 interactions with stakeholders, we explored potential patterns in perceived usefulness as a function of design phase, stakeholder type, and communication form; only stakeholder type showed any relationship with the perceived value of utility by design teams (see Table 5). When the teams interacted with expert end-users, they perceived these interactions to be more useful than compared to other types of stakeholders. For example, Team 6 described their interaction with a group of expert end-users as particularly useful:

TABLE 4 Potential factors impacting usefulness

Design phase	Stakeholder type	Communication form
Problem definition	Sponsor	Interview
Requirements/specifications	Expert end-user	Observation
Concept generation	End-user	E-mail
Concept selection	Other	Survey
Engineering analysis		
Prototyping		
Validation		

TABLE 5 Perceived usefulness per interaction based on a priori coding scheme

Engagement characteristic	Interactions perceived to be Useful	Not useful
Design phase timing		
Problem definition	2	3
Requirements/specifications	19	18
Concept generation	7	4
Concept selection	10	6
Engineering analysis	4	3
Prototyping	2	3
Validation	3	1
Stakeholder type		
Sponsor	20	25
End-user	13	13
Expert end-user	23	7
Other stakeholder	5	4
Communication method		
Interview	55	23
E-mail	1	4
Observation	1	3
Survey	4	3

"It was pretty eye-opening what they were telling us …. They also had good input for concept generation because they have access to the highest technology so they have all these ideas."

Descriptions and frequencies of the five emergent factors that had an impact on students' perceived utility of stakeholder interactions are included in Table 6. The frequencies indicate the number of design teams that displayed a given factor during the semester and the number of instances for which the given factor had an effect on perceived utility.

4.1 | Goal articulation

Students were more likely to find interactions with stakeholders useful if they had developed (informally or formally) clear and explicit goals prior to the interaction. Goals could be specific (e.g., get feedback on the latest design change from a stakeholder) or broad (e.g., understand the use setting for their project). For example, the team creating a clinical simulator for a low-income country visited the university simulation center with the broad goal of understanding simulators and interacting with the simulators available:

> Initially, [we went to the simulation center] to go … see the simulator and be able to interact with the simulators there and [the director] who works there is an expert on simulation and sort of just to interview her on like common simulation practices in the U.S. and like what are the design requirements for her simulator … [the visit] told us a lot about being able to design the pelvic models that we have [in the U.S.] and that drove one of our engineering specs for the [appropriate] size of the [model]. [Team 7; Interview 1]

Team 7 visited the simulation center with broad goals related to gaining a better understanding of what it meant to design a quality simulator. The team considered the interaction useful because of the information they obtained that helped them develop product requirements and engineering specifications even though they did not have very specific decisions they wanted to make as a result of the interaction.

Team 6 described a more specific goal for their interaction with an expert end-user during their project that led to a useful interaction. The team used documentation from international health organizations to develop requirements and then used the interviews with the expert end-user to rank the requirements:

TABLE 6 Factors that impacted perceived utility during student interactions with stakeholders

Factor	Description	Frequency
Goal articulation	The level to which students predeveloped clear and explicit goals for a stakeholder interaction. The goals could be either very specific (e.g., obtaining confirmation on an idea) or very broad (e.g., gathering background on the context of the problem).	7 of 7 teams 24 instances
Stakeholder's expertise	The level of alignment between a stakeholder's expertise and the project topic students pursued. Students noted that interactions were more useful when a stakeholder's expertise closely aligned with their project; for example, a physician who performed research on the topic of the student's design project reliably provided more helpful information than a general practicing physician.	6 of 7 teams 18 instances
Information variability	The level of variation in the information students received from stakeholder interactions. Students found new information less useful when it was highly variable, for example, stakeholders disagreeing or providing different information at various points in the design process.	7 of 7 teams 18 instances
Information applicability	The level of directness which design teams could apply the information obtained from an interaction to a design decision. Teams found interactions less useful when the information gathered was not directly or obviously connected to the design decision at hand.	5 of 7 teams 7 instances
Decision-making responsibility	The level of responsibility design teams assumed when engaging in design decisions. Design teams would often cede control of the decision-making process to stakeholders to improve the utility of interactions, for example, expecting sponsors to decide the proper course of action.	4 of 7 teams 10 instances

> We got more of a ranking of the user requirements than the actual user requirements themselves from the interviews. [Team 6; Interview 1]

Team 6 formulated an explicit goal (ranking requirements by priority level) prior to the engagement, which enabled the team to obtain valuable information from the interaction. Subsequently, the direct applicability of the information to their design process contributed to their perception of the usefulness of the interaction.

Team 4 struggled during the initial phases of the semester because their sponsors did not provide them with unambiguous requirements and specifications or a narrowly defined problem. As the semester progressed, they created very explicit goals for their interactions with their sponsors. For example, during concept selection, they presented their sponsors with two scenarios to force a decision to be made:

> Well, I remember before that meeting, we were discussing the idea of a vacuum and we sat down with one of the grad students and we said "we can either make this enclosure that is supported by all this metal on the inside, which may disrupt your electric field, but you will be able to attain the vacuum that you want or we can make an enclosure that is made out of acrylic so it doesn't disrupt your electric field but you won't be able to have the vacuum." [Team 4; Interview 3]

By presenting only two options to the stakeholder, the students were able to obtain a design decision during the interaction. They perceived the interaction as useful to their design project because it elucidated next steps. The team did not seek out broader information from the interaction nor attempt to use the decision point as a way of learning more about their sponsors' requirements or priorities for the project.

4.2 | Stakeholder's expertise

Students tended to find interactions more useful when a stakeholder's expertise closely aligned with their design project and perceived them as nonuseful when the stakeholder's expertise was less directly related to their project topic. This factor—stakeholder expertise—is a more nuanced version of the "expert end-user" code in the stakeholder type analysis. While interacting with an expert end-user showed a pattern with regards to perceived usefulness, the effect was stronger when the stakeholder's expertise was closely aligned with the specific design decision the team was tackling.

For example, Team 2 identified a professor whose expertise aligned well with their project topic—the design of a medical device that physically interacted with patients' arms. The team developed a concept for assessing the validity of their design and used their interview with an expert end-user to validate it:

> [For] the … pressure [specification], [we performed] a lot of analysis of what's the best model for the human arm. Then we spoke to … a professor here who specializes in tissue mechanics and elastic materials. After talking to him and him saying, "Yeah, that sounds pretty good," we felt pretty comfortable progressing with that. [Team 2; Interview 3]

Despite receiving very little new information from their interaction with this expert end-user, Team 2 perceived the interview to be worthwhile because it validated their approach and the validation came from an end-user with expertise in the field.

As an example of a perceived nonuseful interaction, during one of Team 7's interactions with a stakeholder, they reported that the stakeholder's expertise did not align particularly well with their project:

> We talked to [a doctor] from [Midwestern city], it wasn't the most fruitful conversation but we did talk to her and I guess that we thought that she had more of expertise in this area and the drugs, but her research focuses much more of treatment of cancer rather than screening so it was kind of like, "Your project was awesome. Good luck. But I don't really have too much to help you with." [Team 7; Interview 1]

Ultimately, Team 7 could not guide the interview to produce relevant information. They relied on the physician to provide information that would be relevant but were not able to adjust their interviewing strategy to capitalize on the physician's area of expertise.

4.3 | Information variability

Receiving inconsistent information from stakeholders was a major factor that prevented students from perceiving stakeholder interactions to be useful during design decision-making. The most common form of information variability encountered by teams was conflicting information from stakeholders. Team 4 was designing for multiple sponsors, a group of graduate students with differing areas of research, which produced conflicting design inputs:

> I think we're still honestly getting conflicting messages. One graduate student, he's … the point person, and he's out [of the country], and so he has all of these things that he would like to implement. He'll give us those ideas, and then we'll take them back to [the] other graduate students who are also going to be using the system, and then they'll say "no, this is unfeasible …. And so, because, I think because they're producing slightly different particles … it's been hard to kind of get both voices on the page." [Team 4; Interview 2]

The design team was frustrated with the conflicting opinions among their end-use group and did not feel these interactions were helping them gain a clear understanding of what expectations the end-users had for the system being designed. Team 4 struggled throughout the semester to satisfy the differing requirements of their sponsors/end-users. They stated that dealing with multiple stakeholders with differing opinions was more challenging than the technical aspects of their project. During successive interviews, we saw Team 4 struggle to define the scope of their project and the appropriate requirements. Once the scope of their project was defined, they progressed more smoothly through their design process.

Team 6 also encountered variability in information that made them feel their stakeholder interactions were not useful. When they compared information from different sources and found conflicts, they felt the interactions they had with their sponsor were actually stalling their design process:

> We kind of got conflicting [information] from articles and … from [our sponsor]. Which one should we go with? [Team 6; Interview 2]

Team 6 was unable to synthesize and determine what information was most applicable and appropriate. They also did not take the opportunity to present the conflicting information to their stakeholders and determine why the conflict existed, a practice encouraged in stakeholder interviewing literature (Goguen & Linde, 1993; Kaiya, Shinbara, Kawano, & Saeki, 2005). The team subsequently became somewhat paralyzed by the conflicting information resulting in project stasis at that particular decision point.

4.4 | Information applicability

When information received from stakeholders was not directly or easily applicable to the design decision at hand, most teams perceived the interactions to be not useful. Designing a product for low-income countries, Team 6 had difficulty using the information they gathered from expert end-users who did not know the low-income context. Team 6 described their interaction with physicians at an American medical school:

> Yeah, [the doctors] gave us a lot of ideas that we looked into but most of them, you know, for a [low-income country] would be way too expensive. [Team 6; Interview 2]

Team 6 found that they could not manipulate, generalize, or synthesize the information from their stakeholders to produce useful insights. They also failed to use interviews as an opportunity to dig deeper into the doctors' knowledge and develop a better understanding of the diagnostic aspects of their design project.

Team 2 encountered similar problems applying information from a stakeholder interaction when one stakeholder had a predefined idea of the solution:

> We had a meeting with [a physician], talking about the device in general. He was more interested in a very simple device that can be used and reused for something else …. I get the feeling that he already has a device in his mind. That's not necessarily a bad thing, but I think that might have also influenced how he answered the questions …. It was hard to get him away from that [idea] … even hypothetically [Team 2; Interview 1]

Even though the physician had significant expertise in the topic of interest, Team 2 was unable to elicit information because the physician's suggestions for a solution did not match their precise need statement, and, thus, they considered the interaction to be not useful. The team did not ask the physician why he preferred his solution, a question which could have led to useful information.

Team 3 also struggled with information applicability. This team had an industry partner with a very specific design goal (reduce the cost to manufacture their product by 10–20%); however, the team ran into significant difficulties when developing engineering specifications based upon their interactions with their sponsor. When asked how they went about developing the engineering specifications for their project, the team described the following specific challenges:

> Team Member 1: "[Developing specifications] was very arbitrary when it came to numbers. [Our sponsors] were very good at describing what they wanted, but in qualitative [terms], not quantitative."
> Team Member 2: "We had a lot of trouble putting exact numbers on things when we were looking at the cost reduction [requirement]." [Team 3; Interview 1]

While Team 3 was able to directly apply the information from interviews with their sponsor to the development of product requirements, they felt the information was not as easy to directly translate to the development of the engineering specifications and, thus, considered many of their interactions with the sponsor not useful. This team also struggled to find other information sources to supplement the information that they elicited from their sponsor and demonstrated the most dependence upon a sponsor to inform design decisions during the semester.

4.5 | Decision-making responsibility

Some teams considered interactions with stakeholders as useful when the stakeholders made decisions for the team and not useful when the stakeholders did not make a clear decision for them. For example, Team 5 relied on their sponsor to articulate the project's requirements and specifications:

> I tr[ied] to nail down what [our sponsor] would consider as affordable and even something ... as simple as that, she just didn't have any ideas. [Team 5; Interview 1]

The team believed it was the sponsor's role to develop the specification for the appropriate cost of the design, and when the sponsor did not make this decision for the team, they did not find the interaction to be useful for them. The team did not consider gathering information from the sponsor and combining it with benchmarking and other information sources to generate the requirement's specification. Additionally, design literature suggests that designers should introduce domain knowledge to increase the usefulness of their interactions with stakeholders (Bednar, 2009; Strickland, 2001; Tsai et al., 1997). Team 5 could have introduced domain knowledge in the form of benchmarking data, and this could have led to a more fruitful interaction with their sponsor.

Team 4 encountered a similar difficulty when they realized late in the semester that they had never completely defined the goal of their project. The following excerpt shows their reliance on the sponsor:

> [T]hey didn't know what they wanted in [the project]. And, when we presented our design concepts later on, to the lab .... Even among themselves, they didn't know what they wanted, so it's been really hard to get a grasp on what should we be making. [Team 4; Interview 4]

Team 4 deferred to their sponsors and stakeholders to make a firm decision with respect to which concept should be pursued and how the project scope and requirements should be defined. The team considered this to be part of the role of the sponsor and that they simply needed to collect and record the decision. When the stakeholders were not able to make a clear decision, the team became frustrated and was not sure how to proceed. The team did not perceive that the interaction was useful nor that they gathered information that would help them make the decision in the future. Within design literature, it is commonly known that stakeholders cannot always articulate their wants and needs, and, therefore, student teams must be better prepared to deal with this specific challenge (Deszca, Munro, & Noori, 1999; Mariampolski, 1999).

Perceiving stakeholder interactions as useful when stakeholders made decisions themselves was consistent with Team 7's early behaviors in their project. They relied on stakeholders to make decisions, simply collecting the requirements and not questioning what stakeholders told them. As the semester progressed, the team recognized they needed to be responsible for shaping and questioning the requirements themselves:

> For example, [the requirement that] it must be portable. In the beginning, [two of our design team members] said they heard that [from physicians]. But then [early in the semester], [we asked], "Why is it portable?" and then, "Why does it have to [move around] and who exactly told you that?" [We checked with] studies that had been done on this method and whether it's something that should go [into] the smaller clinics instead of staying in the hospital, [to figure out if] it should be portable. [Team 7; Interview 1]

Team 7 displayed an evolution from a simplistic method of stakeholder interaction (e.g., having stakeholders make decisions) to a more nuanced method of engaging with stakeholders (e.g., collecting multiple opinions and then synthesizing the information) and from a less informed decision-making process to a more advanced one, where they synthesized multiple data streams and critically evaluated their decisions.

5 | DISCUSSION

Below we discuss the study findings in two sections. We first explore the deductive coding findings and interpret them with respect to prior work that has been performed in the field. We also hypothesize as to why some factors may not have proven to be influential in this study, but could prove influential during a typical design project. Then, we discuss the inductive coding findings and what these results might mean for student designers and design course pedagogy.

Within our deductive analysis, only the factor "stakeholder type" showed a relationship with students' perceptions of the utility of stakeholder interactions during decision-making. When engaging with expert end-users, students were more likely to perceive their interactions as useful than when engaging with sponsors, end-users, or others. These results may reinforce prior evidence that during specific developmental stages students prefer to rely on more authoritative information sources (e.g., experts) that more consistently provide direct answers to their design questions (Mohedas et al., 2014a; Wertz, Ross, Fosmire, Cardella, & Purzer, 2011) as opposed to stakeholders such as end-users who may provide a range of differing opinions which would typically be more difficult to synthesize. We also saw similar useful versus not useful interactions with respect to engaging with sponsors. Some of the negative interactions students had with project sponsors may relate to the design team's expectation for what information sponsors should provide (e.g., more information and explicit information). This expectation was not evident with other stakeholders.

The other factors in our a priori coding scheme showed no trends with respect to perceived utility. The factor "communication form" was likely not a major contributor in our analysis because the vast majority of communication between students and stakeholders was through face-to-face interviews. Other forms of communication (such as e-mail, telephone, or web conferencing) were used minimally or only as a way to coordinate face-to-face interviews. We, therefore, cannot say that "communication form" had no influence, but simply that our analysis contained too few instances of the various forms of communication to establish a relationship.

Finally, students did not perceive more or less utility from stakeholder interactions during particular design phases. We posit this is an effect from both the accelerated course timeline and the iterative nature of design. Design phases in the course were well defined and largely linear, but interactions with stakeholders during later phases of design often focused on topics from earlier in the design process (e.g., discussing requirements and specifications during concept selection or prototyping), preventing us from being able to draw specific conclusions with respect to how particular design phases affected teams' perceived utility of stakeholder engagement. In a non-accelerated timeframe this iteration would be expected (e.g., learning that requirements should be changed when a prototype is produced and tested with stakeholders). However, within the course students were often frustrated that their design goals would change or only become clear once they had progressed onto later design phases.

5.1 | Emergent factors that influenced perceptions of stakeholder engagement utility

Teams perceived interactions with stakeholders to be more useful when they had previously defined a specific goal for the interaction. However, teams struggled to engage effectively with stakeholders when the goals of the interactions were more ambiguous and the questions that needed to be asked were not obvious. For example, during requirements elicitation, the challenge and goal of the design work is to reduce the ambiguity of an ill-defined problem (Ashok, David, Gupta, & Wilemon, 1990). Prior research has shown that engagement with stakeholders during front-end design can be effectively used to better define a design problem and identify stakeholders' true wants and needs (Anderson & Crocca, 1993; Islam & Omasreiter, 2005; Kuniavsky, 2003; Neale & Corkindale, 1998). Therefore, students' difficulties with using stakeholder interviews to reduce the ambiguities of their design problem statement represent a significant shortcoming for student design teams during front-end design.

Teams also perceived interviews to be more useful when the stakeholder's expertise aligned closely with the topic of their design project. We observed that most teams engaged with stakeholders who had specific knowledge that was directly related to their design topic and avoided interactions with less well-aligned stakeholders, who had the potential to provide different perspectives and contribute background and contextual information to the students' projects. When engaging with expert end-users, students were able to ask direct, more technically focused questions and allow the expert end-user to synthesize and apply their knowledge to the design context. Gathering information from stakeholders who are not expert end-users in a project's particular area typically requires students to synthesize the information collected themselves and complicates applying it directly to a design decision (Wilson, 1999).

The factors of information variability and information applicability were most pronounced during the more ambiguous design phases such as product requirements elicitation and specification development. During these phases, teams were challenged to synthesize information from stakeholders who tended to provide a wide range of responses (frequently conflicting information) to the teams' questions or provided information that was relevant to their design project overall, but not the decision they were currently trying to make. Despite being exposed to the process of gathering and developing product requirements, several teams struggled to synthesize their data and make informed decisions. Our findings align with and expand upon studies that have identified similar struggles wherein students recognize the importance and benefits of interacting with stakeholders but are challenged to actually implement these processes in a meaningful way (Sugar, 2001). Literature on novice designers and problem solvers has also found that novices oversimplify problems and attempt to rigidly define the procedures and variables needed to solve problems, and ignore the inherent complexities that may exist in a problem or task (Bursic & Atman, 1997; Elio & Scharf, 1990; Rowland, 1992). Some teams appear to have benefited from their struggles with synthesizing diverse information sources because they avoided the problem simplification and rigid problem definition behaviors that other teams exhibited when they were presented with an overly defined problem from their project sponsor; however, a more in-depth longitudinal and holistic analysis is necessary to confirm this trend (Schommer, 1990).

The design teams experienced challenges making use of information obtained from stakeholders that they felt was not directly relevant to the design decision at hand. Teams expressed frustration at being unable to guide stakeholder interviews in ways that would contribute meaningfully to a design decision and were unable to use information not directly applicable to a design decision once gathered. This behavior further illustrates students' difficulties analyzing, synthesizing, and applying information gathered. Rather, it seemed their preference was to apply information transfer (where information can be directly applied without any analysis) (Wilson, 1999). For example, when gathering information from various sources/stakeholders to inform the development of product requirements, one must typically perform information use, but if a designer relies on a single stakeholder to define specific requirements outright, the designer would employ only information transfer. Prior literature points out that stakeholders are not always (or usually) able to describe their needs/wants in terms of product requirements and that it is the job of the designer to translate stakeholder information into product requirements (Ulwick, 2002). Students' expectations of stakeholders must, therefore, be in line with the reality wherein the student designers recognize that converting stakeholder preferences and information gathered into product requirements or design decisions will not necessarily be straightforward and may, in fact, be one of the most challenging aspects of a design process.

Some teams ceded responsibility for design decision-making to stakeholders, most often project sponsors, to determine the best courses of action. The behavior was more evident for teams whose projects originated from an external sponsor such as Team 3, who had a corporate sponsor, and Teams 1, 4, and 5, who were sponsored by research professors, but even teams such as Teams 7 and 2, who defined their own project need statements from clinical observations displayed this behavior occasionally. While deferring to key stakeholders may streamline the decision-making process, design literature emphasizes the need to verify conclusions drawn from interviews and stakeholders with other information sources (Firesmith, 2003; Nuseibeh & Easterbrook, 2000). Some design teams in our study, however, would seek design decisions from their sponsors without considering other information sources. For example, Team 5 originally relied on its sponsor to define most product requirements and specifications, but when the team encountered a specification the sponsor could not define, the members did not know how to proceed. If the teams had treated stakeholder-elicited information as one of multiple information sources when making design decisions (as opposed to a method of directly making design decisions), fewer difficulties might have arisen later in the design process when stakeholders could not provide the specific information they required (as Team 7 demonstrated). Within the literature, similar behavior has been observed, where students tend to view certain information sources as more reliable than others, to the point where students begin to ignore valuable sources of information because they become over reliant upon a single or subset of sources (Alexandersson & Limberg, 2003; Hultgren & Limberg, 2003; McGregor & Streitenberger, 1998).

6 | EDUCATIONAL IMPLICATIONS

Strategies developed by students to increase their success when interacting with stakeholders, such as predefining clear and explicit goals, interacting only with stakeholders with closely aligned expertise, or ceding control of decision-making to stakeholders, were not always aligned with the best practices found in the design literature. Teams may have utilized these strategies to circumvent the most difficult aspects of stakeholder interactions (such as information variability and difficulty applying information to design decisions). Our findings suggest the need for tools and pedagogy to support students in implementing successful strategies for navigating these challenging design activities.

Students struggled with the recommended practice of collecting a diverse set of opinions and synthesizing these to inform design decisions (Goguen & Linde, 1993; Kaiya et al., 2005). For example, some design teams viewed stakeholder interactions as a way to quickly get the "right answer" to the design decisions being considered, a finding we have seen in prior work (Mohedas et al., 2014a). Students were then frustrated when the information gathered was inconsistent, and some teams would then cede control of the design process. Courses encouraging significant stakeholder interaction (e.g., human-centered design, user-centered design, participatory design) could begin with clear explanations of recommended approaches for eliciting critical information and feedback from stakeholders, and building constructive relationships between designers and stakeholders (Dieter & Schmidt, 2012; Strickland, 2001; Tsai et al., 1997). Instructors should emphasize that decision-making is the responsibility of the design team and that decisions are reached after synthesis and analysis of multiple information sources. Additionally, students could potentially benefit from rehearsing stakeholder engagement scenarios with instructors or peers.

Undergraduate students' struggles to effectively perform information synthesis have been well documented, particularly during writing tasks (Flower et al., 1990; Howard, Serviss, & Rodrigue, 2010; McGinley, 1992; Segev-Miller, 2004; Spivey, 1984). To effectively execute stakeholder engagement, students need to overcome the challenges associated with information synthesis while adding stakeholder interaction as a major information source (an information source students are not typically exposed to prior to enrolling in design courses). For example, during the product requirements development stage, instructors could show teams how to document the entire information gathering process and how to work with conflicting or confusing information (teaching some of the tenants of effective qualitative research methods) (Maxwell, 2013). A simple spreadsheet tool could prompt students to document (for each requirement generated) the information that led to the requirement, where it was gathered, information supporting the requirement, and information and sources contradicting the requirement. The emphasis should be placed on executing a thorough process rather than on the requirement itself.

7 | STUDY 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. The demographics of students 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. To minimize these effects, we conducted interviews immediately after each major milestone in the project (minimizing the length of time students were asked to recall), used group interviews, and focused discussion on design decisions made (preventing students from attempting to provide the "right" answers with respect to stakeholder engagement).

One important aspect not studied in 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 in a group setting. Therefore, we do not know the individual students' experiences with stakeholder engagement during design prior to taking the capstone design course. Team members having a natural or developed talent for engaging with stakeholders may have influenced the teams' perceptions regarding the usefulness of stakeholder engagement when making design decisions.

8 | CONCLUSIONS

This study identified specific factors that influenced whether undergraduate design teams perceived stakeholder engagement as useful during design decision-making. Factors included the stakeholder type, the level to which students predeveloped clear and explicit goals for an interaction, the level of alignment between a stakeholder's expertise and the project topics, the level of variation in the information students received from stakeholders, the level of directness with which design teams could apply information gathered to a decision, and the level of responsibility design teams assumed when engaged in decision-making. The factors identified elucidate specific areas in which students struggled when collecting and incorporating stakeholder information into design decisions and where they potentially missed out on the myriad benefits from this engagement. Pedagogy and support developed to help students overcome several key challenges (e.g., information collection, information synthesis, decision-making processes) associated with stakeholder engagement may help students obtain the benefits associated with effective engagement and motivate them to engage in human-centered design.

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