122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Paper ID #13654

Valuing and engaging stakeholders: The effects of engineering students' interactions during capstone design

Ibrahim Mohedas, University of Michigan

Ibrahim Mohedas is currently a Ph.D. candidate in the Department of Mechanical Engineering at the University of Michigan. He received his B.S. in mechanical engineering from the University of Texas at Austin in 2011. His research focuses on the design of medical devices for resource limited settings, particularly related to the use of design ethnography in developing these technologies. He works in the Laboratory for Innovation in Global Health Technology (LIGHT) and is co-advised by Shanna Daly and Kathleen Sienko.

Grace Louise Cravens, Sienko Research Group

Grace Cravens is a sophomore undergraduate student at the University of Michigan studying Industrial & Operations Engineering. She is from St. Joseph, MI, and has worked for Sienko Research Group since 2013.

Dr. Shanna R. Daly, University of Michigan

Shanna Daly is an Assistant Research Scientist and Adjunct Assistant Professor in Engineering Education in at the University of Michigan. She has a B.E. in Chemical Engineering from the University of Dayton (2003) and a Ph.D. in Engineering Education from Purdue University (2008). Her research focuses on strategies for design innovations through divergent and convergent thinking as well as through deep needs and community assessments using design ethnography, and translating those strategies to design tools and education. She teaches design and entrepreneurship courses at the undergraduate and graduate levels, focusing on front-end design processes.

Dr. Kathleen H. Sienko, University of Michigan

Kathleen H. Sienko is a Miller Faculty Scholar and Associate Professor of Mechanical and Biomedical Engineering at the University of Michigan (UM). She earned her Ph.D. in 2007 in Medical Engineering and Bioastronautics from the Harvard-MIT Division of Health Science and Technology, and holds an S.M. in Aeronautics & Astronautics from MIT and a B.S. in Materials Engineering from the University of Kentucky. She directs both the Sensory Augmentation and Rehabilitation Laboratory (SARL) and the Laboratory for Innovation in Global Health Technology (LIGHT). SARL focuses on the design, development, and evaluation of medical devices, especially for balance-impaired populations such as individuals with vestibular loss or advanced age. LIGHT focuses on the co-creative design of frugal innovations to address healthcare challenges in resource-limited settings. Prof. Sienko has led efforts at the University of Michigan to incorporate the constraints of global health technologies within engineering design at the undergraduate and graduate levels. She is the recipient of a CAREER Award from the National Science Foundation, a Teaching Innovation Prize from the UM Provost, and a UM Undergraduate Teaching Award. While at MIT, she was a winner of the MIT $50K Entrepreneurship Competition.

Valuing and engaging stakeholders: The effects of engineering students' interactions during capstone design

Introduction and Background

Design is a critical component of engineering students' education and an essential skill in engineering.[1,2] Recently, human-centered design processes have been featured in the design practice literature, because the processes result in usable products that are better able to meet the needs and wants of stakeholders.[3,4] Human-centered design directs the designer to focus on the stakeholders affected by the design and the broader context in which the product will be used (as opposed to the technology being developed).[5] To implement human-centered design processes the designer needs to interact with or to involve stakeholders in the design process itself in order to obtain a deep understanding of the stakeholders and the future product's context of use.

While customers and end-users are the most commonly studied stakeholder groups cited by the design literature, stakeholders may also include retailers, manufacturers, distributors, maintenance personnel, etc.[6] Typically, designers consult stakeholders during the early stages of design in order to define product requirements.[7–10] More recently, studies have emphasized the role of stakeholders in other phases of product development, such as concept generation, concept evaluation, and prototype assessment.[11–14] For example, a study on concept generation found that customers developed more innovative design solutions with respect to originality and user value than professional designers.[15]

While interaction with stakeholders in design has been shown to be beneficial, it is not a simple process and must be carefully executed to be beneficial.[16] The push towards human-centered design in industry has been mirrored in engineering education as design courses have increasingly incorporated human-centered design processes to prepare students for the changing design processes they will encounter after graduation.[17,18] Incorporating stakeholder interaction into the design process can be challenging for students who do not typically encounter these tasks during early engineering coursework. Prior research on student understanding and use of stakeholder interaction during the design process has found that students do not always interact with stakeholders successfully (as outlined in the design practice literature).[19–21] Some of the difficulties student encounter when attempting to interact with stakeholders causes them to neglect or dismiss stakeholder interaction during design.[20,22] Thus, more research is needed to develop pedagogy for teaching these complex processes.

This study sought to address this gap in the literature by determining what students perceive the role of stakeholders should be during the design process and identifying the design project traits that facilitate learning the value of human-centered design processes.

Research Design

Study Purpose

The goal of this study was to determine how student perceptions of stakeholders differed before and after their capstone design experience, and to determine if and how the students' interactions with stakeholders during the semester changed their perceptions. We also explored how different design project traits may have affected the level of stakeholder interaction teams conducted during the capstone design course.

Participants and Context

The study participants consisted of 23 students composing seven design teams. The students were enrolled in the capstone design course for Mechanical Engineering. All students attended one common weekly lecture. Three professors mentored the eight design teams (Teams 1and 6 by one professor, Teams 7, 8, 9, and 10 by a second professor, and Team 18 by a third professor).

Data Collection

Data collection consisted of pre- and post-course student surveys and interviews during the capstone course. Through the pre-course survey, we gathered background information including major, gender, year of study, prior design courses taken, and extracurricular design activities. Both surveys had nine open-ended response questions as shown in Table 1. Students completed the pre-course survey by the third week of the course.

Table 1: Open-ended response questions for pre- and post-course survey

Question Number	Question
1	What role do you think stakeholders should have during product design?
2	List up to three phases in design where you believe that interacting with stakeholders would produce benefits? If you list multiple phases, rank them in order of importance and justify your reasoning.
3	Identify benefits to interacting with stakeholders when designing.
4	Identify challenges to interacting with stakeholders when designing.
5	List up to 5 methods you would employ to gather user requirements? If you list multiple methods, please rank them in order of importance.
6	What challenges might you face when performing these requirements gathering method(s)? How would you overcome these challenges?
7	With respect to the user requirements and engineering specifications you developed for your design project: Specify the type of data you collected and from where this data came from (also speak to data you haven't collected yet, but hope to in the future).
8	Specify your methodology for collecting the data.
9	Specify how you analyzed or brought together your data to develop user requirements and engineering specifications.

For the post-course survey, the participants' original responses were returned and the participants were allowed to add, change, or delete their original responses. Microsoft Word with Track Changes was used to ensure that all changes were noted. We distributed the post-course surveys during the final week of the course and they were collected within two weeks.

During the semester, we conducted four semi-structured interviews with each design team. Interviews focused on each teams' design approach and the design decisions made. The interviewer asked follow-up questions whenever a student mentioned any form of stakeholder interaction (i.e. meetings with sponsors, interviews with end-users, etc.). Interview transcripts were transcribed for analysis.

Data Analysis

Nvivo 10 was used to analyze all pre- and post-course survey data. We used an iterative inductive coding procedure to identify the levels of stakeholder interaction considered beneficial by the students.[23] Preliminary analysis revealed the three-level coding scheme shown in Table 2. We then applied the coding scheme to all survey responses to determine the level of stakeholder interaction students cited as useful in their pre-course and post-course survey responses. Each set of survey responses was placed into one of the three levels, or between the levels if characteristics from two levels were observed. The results were then grouped together per each student's design team.

Table 2: Coding scheme used to establish the level of interaction with stakeholders that students perceived as beneficial during design

Level	Definition
Limited stakeholder interaction	Students describe a limited role for stakeholders during certain design phases. Students mention few, if any, benefits to interacting with stakeholders during the design process.
Moderate stakeholder interaction	Students recognize that interacting with stakeholders is beneficial during the design process. Students mention one to three specific design phases where stakeholders should play a role (the most common phases include problem definition and development of user requirements).
Extensive stakeholder interaction	Students describe a large role for stakeholders during the design process (e.g., describing stakeholders as "very" important or "critical" during design). Students do not restrict stakeholders to specific design phases, but instead, describe their involvement as continuous during the design process.

The study team then applied the same coding structure (Table 2) to assess the level of stakeholder interaction executed by design teams during the capstone design course; this was an analysis of what design teams actually did during the course project, as opposed to the pre- and post-course survey analyses that assessed what students perceived as beneficial. The design team interview transcripts were analyzed using a narrative analysis technique where the interviews were condensed into two-page narratives focusing on the team's stakeholder interactions during the semester. The condensed narratives were combined with final design reports to determine the level of stakeholder interaction (limited, moderate, or extensive) employed by the design teams. The assessments represented a determination of a team's actual level of stakeholder interaction versus the perceived level of utility described in each student's pre- and post-course surveys.

Findings and Discussion

The findings are presented in three sections below. First, we describe the two major trends observed in how a team's perceptions of stakeholders' roles changed as a result of their capstone design course. Second, we present a case analysis of three design teams who displayed varying levels of perceptions before and after the course and who implemented varying levels of stakeholder interaction during the semester. Third, we discuss the key project traits that may have contributed to higher levels of stakeholder interaction for design teams during the semester.

Types of Changes Students Made in the Post-course Surveys

The pre- and post-course surveys revealed changes in students' perceptions regarding the utility of stakeholder interaction during design. Three levels were identified that represent the perceptions of stakeholder interaction during design: 1) limited stakeholder interaction, 2) moderate stakeholder interaction, and 3) extensive stakeholder interaction. Table 3 gives example responses by different students that illustrate the three levels.

Table 3: Varying levels of students' perceptions of the utility of stakeholder interaction

Level	Example Responses
Limited stakeholder interaction	"Design should be left to those who are specifically qualified to design the product. Suggestions are always a good thing but they should not tell the designer how to do their job."
Moderate stakeholder interaction	"[Stakeholders] should have primary input on user requirements. They should also be in an advisor role as the project progresses, giving feedback on if the engineering [specifications] developed by the team satisfactorily fulfill the user requirements." "The stakeholders demonstrate the needs that the product must satisfy. Their input determines whether the product is successful in accommodating those needs." "They should provide insight into user requirements. They also should contribute during concept generation; specifically what they think will or will not work about designs."
Extensive stakeholder interaction	"I think stakeholders should play a pretty large role when it comes to product design. They are the ones who have the idea in mind of what the product should look like so it is important that they play a large role when it comes to design." "Stakeholders should be informed along the way during each step of the design process to make sure everything is up to their standards. They should sign off on any work that the design team does before they begin the next phase of design." "I think the stakeholder should be a very important part of product design. They should have more of a "non-engineering boss" position (assuming they are not an engineer). This way, they can watch the progress of the design and give input, but not unnecessarily bias the engineers or limit their ideas."

Through the analysis of students' pre-course surveys, post-course surveys, and design team interviews, two distinct patterns emerged with respect to the level of stakeholder interaction they experienced during the design course and how their perceptions of stakeholder interaction did or did not change after the course. For teams whose processes are represented by the first pattern, their expectations of how stakeholders should be involved in the design process were not met during their capstone design work and their perceptions of stakeholder interaction in design did not change after the course. For teams' experiences who are represented by the second pattern, their expectations of how stakeholders should be involved in the design process were met or exceeded during their capstone design work and their perceptions of the level of stakeholder interaction necessary in design increased after the course. These patterns are represented in Figure 1.

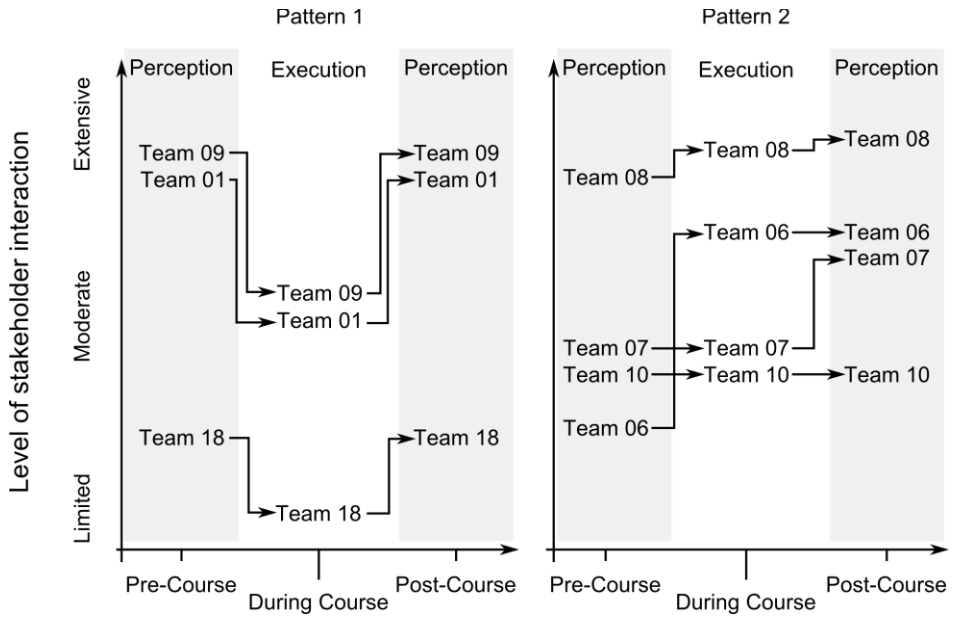

Figure 1: Design team perceptions of the level stakeholder interaction that is beneficial during design (pre- and post-course surveys) and design team's actual level of interaction (in course) with stakeholders during the capstone design course.

Team Cases

The following case examples provide an illustration of how design team's perceptions changed as a result of the design course and how the students interacted with stakeholders during the course.

Team 1

Team 1 began the semester with the perception that stakeholders should be highly involved in the design process. For example, a Team 1 student wrote:

> "I think stakeholders should play a pretty large role when it comes to product design. They are the ones who have the idea in mind of what the product should look like so it is important that they play a large role when it comes to design."

Similarly, another Team 1 student discussed the specific role of stakeholders:

> "I think that the stakeholders should have a supervisory role in the product design. They should be able to periodically review the design to ensure that their requirements are being met but they should not have direct control over the design of the product itself."

During the semester, Team 1 developed laboratory equipment for a biomedical engineering research group on campus. The project sponsor was an engineering professor and the end-users were a group of graduate student researchers. Team 1's project sponsor supplied a list of the design project requirements. When asked about their sponsor during a study interview, one student commented:

> "A lot of it for us was easy because [our sponsor] had a very clear idea of what exactly she wanted. She was pretty solid on her input of requirements, so it was pretty easy to just add [engineering specifications] onto that."

Most teams had to gather product requirements on their own, while this team was supplied their requirements directly by their sponsor. This difference may have led Team 1 to interact less with their defined end-user group (graduate student researchers) because they believed they already had the necessary information to design the equipment. Team 1 only mentioned visiting the professor's lab once during the course. Team 1's meetings with its sponsor were mostly devoted to progress updates and obtaining the sponsor's final decisions about team ideas. During the semester, Team 1 often spoke about how its sponsor would change the product requirements. During the second interview with the design team, one student stated:

> "…she came to us with some more information because she'd just gone to a conference. So it changed our design a little bit, in the sense that we needed to have a broader range of capability."

During the final interview with Team 1, another student stated:

> "I mean, there was some stuff that [the lab] kind of thought of late, [features] that they sort of thought about and they wanted added in… they didn't really tell us about [the features] until way into the designing process."

These thoughts were reflected in the students' post-course surveys. For example, one Team 1 student added a caveat to their pre-course response about how stakeholders should have a prominent role during design:

> "Stakeholders should have a large role but they also need to understand the entire design process and know what kind of limitations there are."

The same Team 1 student also changed their pre-course response to Question 4 (identify challenges to interacting with stakeholders when designing):

> "It is important that all parties are on the same page when prototyping begins so that there are no unnecessary design changes that could waste time and money."

Another Team 1 student added to his/her original response. Below the original response is shown in black and the post-course change is has been bolded and italicized.

> "Stakeholders should have the role of making sure that the overall product is effective and meets requirements as set from the beginning. They should also make sure that they will be able to market and sell the product in order to receive a return for their work. ***I still agree with all of this but stakeholders should also make every attempt to set up a reasonable timeline and be aware of foreseeable timing/money issues that might come up during the project.***"

Analysis of the changes Team 1 students made to their survey revealed that their perceptions of the role of stakeholders did not change as a result of the course. We also observed that the team did not interact with stakeholder during the semester in the way they described during their pre-course survey. Towards the end of the semester and in post-course survey responses, students noted many frustrations associated with designing for stakeholders, but few benefits. This imbalance could have contributed to the lack of change in the students perceptions of the role stakeholders should have during design.

Team 7

At the beginning of the semester, Team 7 described a moderate level of interaction with stakeholders during design, emphasizing specific phases where stakeholders should be involved. This was captured in the students pre-course survey responses, for example, one student mentioned that the stakeholders' primary role would involve defining user requirements:

> "They should have primary input on user requirements. They should also be in an advisor role as the project progresses, giving feedback on if the engineering [specifications] developed by the team satisfactorily fulfill the user requirements."

Another Team 7 student discussed how stakeholders motivate the need for design projects:

> "The stakeholders demonstrate the needs that the product must satisfy. Their input determines whether the product is successful in accommodating those needs."

Team 7's pre-course survey responses demonstrated an understanding of how stakeholders can be involved during design, but all of the team's students also believed that stakeholder interaction was predominantly limited to certain design phases, such as development of product requirements, and specific roles, such as motivation for a design project.

During the semester, Team 7 designed a medical device meant for direct consumer purchase. The team's sponsor was a university physician who developed Team 7's design problem statement. The project had a well-defined, although not necessarily easily reachable, end-user group. Because some of the sponsor's research interests aligned with the goal of the project, the sponsor already had certain expectations about the technical requirements of the design.

Team 7 relied heavily on its project sponsor during the development of user requirements and engineering specifications. They originally developed a survey for end-users that they hoped would provide direct feedback about requirements and specifications from other stakeholders, but this survey could not be distributed due to logistical challenges. At mid-semester, the course instructor told the team to meet with end-users (and proxy end-users, i.e., people who share many common traits with actual end-users but who are more available) to discuss the concepts the team had generated and gather feedback. Based upon the feedback from these discussions with end-users, Team 7 had to dramatically redesign their device. During interviews at the end of the semester, Team 7 discussed how it should have developed prototypes and collected feedback from stakeholders far earlier in the design process.

At the end of the course, Team 7 made significant changes to their responses during the post-course survey. One Team 7 student expanded the role he/she believed stakeholders should have during design, stating:

> "As the project progresses, they can also offer valuable input on design changes made by the team as well as design changes the team is considering."

The same student added "Interviewing potential users" to the list of methods for gathering user requirements (a method not mentioned in the pre-course survey). Another Team 7 student stated:

> "When a prototype is developed, it should be presented to stakeholders to determine its efficacy…Checking in with stakeholders during the design process ensures that the product is on track with their needs."

After the course, the students realized the benefit of engaging with stakeholders after the initial needs assessment, particularly once a prototype has been developed and can be used to provide feedback on the design. The students, however, mentioned that "another challenge in some projects is lack of access to stakeholders, whether restricted by geography, number, or time." The students might have been able to obtain more feedback on their original design concepts (and thus prevent the need for a drastic redesign) if they had interviewed end-users earlier in the process, but logistical obstacles prevented this interaction.

Team 7 began the semester with the perception that a moderate level of stakeholder interaction is beneficial during the design process, but ended the semester with the perception that stakeholders should be involved throughout the design process and play a large role. While they initially resisted opportunities to interact with stakeholders early in the semester, they eventually obtained direct feedback on their device from end-users and this led to dramatic changes in their design. This experience seems to have been the catalyst for the changes in the students' perceptions.

Team 6

Team 6 began the semester with the perception that interacting with stakeholders during design is important, but only needed to a limited extent. For example, in the pre-course survey one student stated:

> "Stakeholders should provide the requirements and some specifications of what they want in their design. They should be able to have input on design selection but should not be have say in between iterations of potential designs."

Another Team 6 student defined a similar limited role for stakeholders:

> "They should check up on the design and manufacturing process from time to time to ensure they are getting the results they asked for but not trying to lead the design team in every step."

Another Team 6 student also believed that stakeholders should have a limited role: "…they will be higher level reviewers and be most concentrated on the financial effects of the designs."

Throughout the pre-course surveys, the students on Team 6 acknowledged that stakeholders had a well-defined role in design, but that the role was limited.

During the semester, Team 6 designed a piece of manufacturing equipment for a research laboratory in the College of Engineering. The team was sponsored by the professor who oversaw the laboratory. The end-users were a group of graduate student researchers (one of which would be the principle end-user).

Team 6 interacted frequently with its sponsor and end-users in order to guide the project. Team 6 found that the end-users did not all have the same wants and needs. Team 6 overcame this problem by holding many meetings with the different graduate student end-users who would eventually use the equipment. Team 6 also noted that interacting individually with the end-users was not useful, because the team constantly received contradicting information from different end-users. In contrast, meeting with all their end-users at once allowed the end-users themselves to reach consensus, thus giving Team 6 a clearer direction. This technique allowed Team 6 to make efficient use of meeting times and prevented straying too far from the end-users' intent for the project.

This experience seems to have influenced Team 6's perceptions of stakeholders during the design process as shown in their post-course survey responses. For example, one student stated that "[stakeholders] may…provide input and want to participate in the design process." This student recognized that stakeholders could engage in the design process in a participatory role, significantly expanding upon his prior perceptions. This same student significantly changed his response to Question 3 (Identify benefits to interacting with stakeholders when designing):

> ~~"I wouldn't call it a benefit~~. ***I would consider it absolutely essential. We are designing for them.***"

This student originally could not think of any benefits to interacting with stakeholders during design, but completely changed their belief after the course. Another student made similarly significant changes:

> "[Stakeholders] should be able to have input on design selection ~~but should not have a say in between iterations of potential designs~~ ***and should be able to refine their expectations throughout the design process. They should also provide feedback after [each] new iteration of the design has been completed."***

Team 6 students also discussed how they were able to overcome the challenges involved with designing for diverse stakeholders. For example, one student noted that an important key to gathering requirements effectively was to "create a culture of constant communication to identify and resolve potential problems before they arise."

In pre-course survey responses, Team 6 described a limited role for stakeholders during design. During the course, the team had to interact with stakeholders much more extensively in order to satisfy the needs and wants of the various graduate student researchers who had differing

research goals. As a result, Team 6's perception of how important stakeholder interaction is during design greatly increased upon completion of the capstone design course (as shown in their post-course survey responses).

Key Project Traits

The analysis above showed that design teams whose level of stakeholder interaction was equal to (or exceeded) their pre-course expectations were more likely to increase the level of stakeholder interaction they perceive as necessary by the end of the design course. Additionally, several key projects traits emerged from the in-depth analysis of Teams 1, 6, and 7 whose presence or absence may have contributed to the level of stakeholder interaction teams' conducted during the semester. The team narratives of the remaining four teams were then used to confirm whether these key project traits were evident in multiple teams from the sample of seven. Table 4 presents the traits identified and demonstrates how they impacted specific teams.

Table 4: Key project traits that facilitate stakeholder interaction

Trait	Explanation
Easily accessible stakeholders	Teams 7 and 18 had extensive difficulties accessing their stakeholders. These teams tended to fall back on their project sponsors for the development of requirements and specifications (and encountered major difficulties when their sponsors were not able to provide the required information).
Clearly defined stakeholders	Teams 1 and 18 had extensive difficulties defining stakeholders that were not their sponsor (for example, they did not attempt to define an end-user group). Teams 7 and 8, however, were able to clearly define their end-users and other stakeholder groups (in addition to their sponsor) and they consulted these end-users and stakeholders during the design course.
Existence of multiple key stakeholders	Design teams with dominant sponsors (such as Teams 1 and 18) were less likely to interact with other stakeholders who may have provided relevant information. In contrast, Teams 6 and 10 had a wide range and diverse set of end-users and stakeholders, requiring them to increase their level of stakeholder interaction to adequately understand all of the stakeholders' wants and needs.
Existence of proxy-stakeholders	Some design teams (such as Team 9) became fixated on specific stakeholders they defined as the most important. Other teams, such as Team 7 and 8 were able to deviate from their "true" stakeholders and use proxy-stakeholders to gain relevant information in an easier fashion.
Opportunity to perform context assessment	Teams 6, 8, and 9 were able to perform an in-depth context assessment and they commented that it was one of the most valuable information sources during the project. This context assessment formed a basis on which design teams later performed further stakeholder interaction.
Opportunity to refine project scope / definition	Teams 8 and 10 had more flexibility to refine their project definition than the other teams and used stakeholder interaction to provide clarity for their need statements and user requirements/engineering specifications. Team 18 however, had an extremely well-defined project from the beginning of the semester, reducing their perceived need to interact with stakeholders.

Three of the design teams conducted more limited stakeholder interactions during the course than they perceived was appropriate prior to the beginning of the course. Similarly, a previous study found that design students who encountered challenges when interacting with stakeholders later reduced their utilization of this resource as their projects progressed.[20] Additionally, some of the challenges to stakeholder interaction found in this study, such as gaining access to the primary stakeholders and curtailing stakeholder interaction after gaining what students' perceive as enough information, have been previously identified in the literature. [20,22]

Implications

The findings of our research suggest several implications for design education. We have shown that changes in student perceptions of stakeholder utility are not only dependent on the level of stakeholder interaction they perform during a design course, but also on their pre-course expectations of stakeholder interaction. Instructors looking to affect student perceptions of stakeholder utility during design could use this finding to guide student development. For example, design teams might be required to develop documentation where they specify how stakeholders should be involved during their design projects. Teams could then use this documentation to guide their implementation of stakeholder interaction during the semester, increasing the likelihood that the team's execution of stakeholder interaction (during the course) matches their expectations of stakeholder interaction (defined before the course). Incorporating stakeholder interaction into curricular goals might be necessary, as a prior study showed that while design teams might develop ambitious plans for stakeholder interaction, they are likely to drastically reduce the level of stakeholder interaction they conduct during the design course[24].

Additionally, we have identified several project traits (Table 4) that may facilitate increasing the level of stakeholder interaction during design. This demonstrates the importance of project selection when developing design courses that seek to emphasize specific design processes (such as human-centered design). The project traits identified here could form the basis for additional research in the area of human-centered design pedagogy or be used to formulate more appropriate design projects for instructors seeking to emphasize human-centered design processes within their own courses.

Limitations and Future Work

Limitations of this study included timing of participant recruitment for the team interviews, and advance knowledge of project assignment. Students were not recruited individually, but were recruited as participants of design teams (at least three out of four team members were required to participate). Having been already placed onto design teams, students' pre-course survey responses may have been influenced by their peers. Similarly, students had already been assigned their semester design projects when they filled out their pre-course survey. The students may have answered the pre-course survey with their current design project in mind (i.e., not their general view of stakeholder interaction during design but their view of stakeholder interaction with respect to their current design project). These two limitations may help to explain why students on teams shared similar perceptions of stakeholder interaction during design (allowing us to analyze perceptions at the team level). Future studies could recruit students to complete pre-course and post-course surveys individually and subsequently assess the level of stakeholder interaction executed during the semester via design reports. This would allow for a more comprehensive study to be conducted and perhaps lead to additional critical project traits.

Conclusions

Human-centered design processes are becoming more pervasive in both industry and academia. Performing human-centered design challenges students to make design decisions through the use of stakeholder research and not rely on their prior assumptions. The skills necessary to perform human-centered design (such as observing/interviewing stakeholders, collecting/analyzing qualitative and quantitative end-user data) are not necessarily emphasized during early engineering coursework. Design courses, and capstone design courses in particular, are the ideal opportunity to teach human-centered design processes and emphasize the role that stakeholders can have during the design process. In this study, however, we have shown that students' perceptions of the utility of stakeholder interaction during design do not always change as a result of capstone design courses. In particular, we have shown the importance of matching the level of stakeholder interaction during a design course with students' pre-course expectations. The study also identified key project traits that may contribute to increasing students' level of stakeholder interaction during design courses and, thus, would enable design courses to emphasize human-centered design processes. These project traits could be used to formulate design projects for human-centered design courses and establish a basis for future research in this area.

Acknowledgments

This work was supported by the University of Michigan's Rackham Merit Fellows program, the National Science Foundation's Graduate Research Fellowship program, the National Science Foundation's Research Initiation Grants in Engineering Education, the National Science Foundation's CAREER program (GARDE-0846471), and the University of Michigan Center for Research on Learning and Teaching's Investigating Student Learning Grant. The study team thanks the students who volunteered as study participants and Ann Stewart for her help in editing.

Bibliography

1. Simon HA. *The Sciences of the Artificial*. 3rd ed. London: MIT Press; 1996.
2. Dym C, Agogino A, Eris O, Frey D, Leifer L. Engineering design thinking, teaching, and learning. *J Eng Educ*. 2005;94(1):103–120.
3. Jokela T. The standard of User-Centered Design and the Standard Definition of Usability: Analyzing ISO 13407 against ISO 9241-11. In: *ACM International Conference Proceeding Series*.; 2003.
4. Zhang T, Dong H. Human-Centred Design: An Emergent Conceptual Model. In: *Proceedings of Include2009*. London: Royal College of Art; 2009:1–7.
5. Steen M, Koning N De, Pikaart A. Exploring human centred approaches in market research and product development – three case studies. In: *Proceedings of the conference on Dutch directions in HCI*.; 2004:1–4.
6. Neale MR, Corkindale DR. Co-developing products: Involving customers earlier and more deeply. *Long Range Plann*. 1998;31(3):418–425. doi:10.1016/S0024-6301(98)80008-3.
7. Griffin A. *Drivers of NPD Success: The 1997 PDMA Report*. Chicago, IL: Product Development & Management Association; 1997.
8. Haman G. Techniques and tools to generate breakthrough products. In: Rosenau Jr MD, ed. *PDMA Handbook of New Product Development*. New York: John Wiley and Sons; 1996:167–178.
9. Eliashberg, Lilien R. Minimizing Technological Oversights : A Marketing Research Perspective. *Technol Innov Overs foresights*. 1997;3004(814):214.

10. Rangaswamy A, Lilien G. Software tools for new product development. *J Mark Res*. 1997;34(1):177–184.
11. Neale MR, Corkindale DR. Co-developing products: Involving customers earlier and more deeply. *Long Range Plann*. 1998;31(3):418–425. doi:10.1016/S0024-6301(98)80008-3.
12. Lilien GL, Morrison PD, Searls K, Sonnack M, Hippel E Von. Performance assessment of the lead user idea-generation process for new product development. *Manage Sci*. 2002;48(8):1042–1059.
13. Von Hippel E. The dominant role of the user in semiconductor and electronic subassembly process innovation. *IEEE Trans Eng Manag*. 1977;EM-24(2):60–71. doi:10.1109/TEM.1977.6447336.
14. Urban GL, von Hippel E. Lead User Analyses for the Development of New Industrial Products. *Manage Sci*. 1988;34(5):569–582. doi:10.1287/mnsc.34.5.569.
15. Matthing J, Sandén B, Edvardsson B. New service development: learning from and with customers. *Int J Serv Ind Manag*. 2004;15(5):479–498. doi:10.1108/09564230410564948.
16. Kujala S. User involvement: a review of the benefits and challenges. *Behav Inf Technol*. 2003;22(1):1 – 16. doi:10.1080/0144929021000055530.
17. Oehlberg L, Leighton IAN, Agogino A. Teaching Human-Centered Design Innovation across Engineering , Humanities and Social Sciences. *Int J Eng Educ*. 2012;28(2):484–491.
18. Klatsky GJ. User centered design of human factors class projects. *Proc Hum Factors Ergon Soc Annu Meet*. 1998;42(7):611–615. doi:10.1177/154193129804200703.
19. Sugar WA. What is so good about user-centered design? Documenting the effect of usability sessions on novice software designers. *J Res Comput Educ*. 2001;33(3):235 – 250.
20. Scott JB. The Practice of Usability: Teaching User Engagement Through Service-Learning. *Tech Commun Q*. 2008;17(4):381–412. doi:10.1080/10572250802324929.
21. Mohedas I, Daly SR, Sienko KH. Requirements development: approaches and behaviors of novice designers. *J Mech Des*. 2015.
22. Mohedas I, Daly SR, Sienko KH. Design Ethnography in Capstone Design: Investigating Student Use and Perceptions. *Int J Eng Educ*. 2014;30(4):888–900.
23. Creswell JW. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. 4th ed. Thousand Oaks, CA: Sage Publications; 2013.
24. Mohedas I, Daly SR, Sienko KH. Gathering and Synthesizing Information During the Development of User Requirements and Engineering Specifications. In: *121st ASEE Annual Conference & Exposition*. Indianapolis; 2014.