Teaching User-Centered Design to Senior Engineering Students

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Abstract

Introducing a user in the capstone design course is beneficial for the students, but not without challenges. An external user, who ultimately will take possession of and utilize the designed product, helps ensure that the project is relevant, usable and within budget and timeline. He/she also enhances the teams' responsibility to deliver a product that not only performs a task, but also complies with requirements established early in the design process. It brings the experience closer to a real-world situation that students should expect to face throughout their careers: being confronted with stakeholders during the design process.Students are faced with both the technical challenges of the design project and the uncertainties of dealing with a user not necessarily familiar with the engineering process. We report on the experience of, over two years, training a total of four teams of students who designed assistive devices for users with disabilities. Student teams, consisting of 2 to 5 students, were matched with a user, and designed a device to help him/her perform everyday tasks. Teams were responsible for setting up regular meetings with the user, design and deliver the device according to the user's preferences. Throughout the process, both students and stakeholders reported on the project's progress and challenges. We focus on the development of the communication process: the tools that were leveraged to monitor it and the problems that arose. We also discuss strategies for supporting the students through the design process when the user is an integral part of it.

Keywords: *User-centered design, capstone project, communication*.

1. Introduction

Senior design or capstone projects are in many engineering curricula the main, if not the only, course where students are asked to integrate the knowledge acquired throughout their undergraduate studies in order to devise and build a device that will address a real-world problem, and thereby demonstrate their abilities in engineering. Being their first experience of this magnitude, it can often be an overwhelming. Students go through the process of choosing a project, performing market research, proposing a solution and setting specifications, and then focus their efforts on building a working device. However, it is a common occurrence that the technical challenges during the design and development process overcome initial intentions, leading to designs that maybe working, but would in a real-world setting be of very limited marketability. Here, the design has lost track of its original goal: fulfil a real-world need, and do so in a manner that is attractive to a potential customer.

This same occurrence is not uncommon in more real-world settings. Even during a commercial development process, it is common for designers not to engage the user in the process, but rather follow their own perceptions of user needs. As a result, there is an abundance of products that the average consumer would deem too complicated to use or that do not address an obvious customer need; both shortcomings may compromise the marketability and the eventual success of the design.

Customer-centered design is a critical aspect in product development. [1] [2] However, we often run into the misconception that the designer, based on either personal or work experience, can infer the customer's needs or wants, possibly better than the customers themselves. User-centered design practices try to

overcome this misconception. As discussed by Maguire [3], a main principle in the user-centered experience is the active involvement of the user and a clear understanding of the user's and task requirements; such an involvement results in a better final product. [4]–[6]
This issue becomes even more critical in the design of assistive technology devices. In assistive technology, independent living relies on a series of devices, which increase the quality of life of the client. However, when reporting on assistive technology use, long-term users discontinued use of devices due to two factors: (1) loss of relative advantage and (2) lack of consumer involvement. Both factors compromise the commercial success probabilities of a device, and they both point to the same fundamental problem: a device designed in order to address a specific, real-world, problem, but without taking the users' point of view into account.

In this paper, we report our initial approach to teaching students user-centered design in the context of a capstone design class. For this study, student teams were paired with a user, who in our case was a member of the university community with disabilities (PwD), and were tasked to build an assistive technology device to help the user with everyday tasks. We aimed at having the user as much involved as possible throughout the design process, so that, at the end of the two-semester long course, the user would receive and *use* a device according to his/her specifications.

This project is based on the hypothesis that by incorporating the input of a user throughout the senior design process, students will benefit from the user's feedback and produce a design or a prototype that has the potential of yielding a marketable product. Furthermore, we expect that by going through the challenges of a user-centered design process in a "protected" environment, with the readily available support from a facilitator team, may help the students understand both the challenges and the rewards of user-centered design.

2. Related theory / literature

The term user-centered design is mainly in use in computer science and software engineering, where the creation of user-friendly software interfaces has been a crucial effort over the last thirty years. [7] Hindsight gained from this field shows that usability is a critical factor for product success; however, this road was not without challenges. While their benefits are well-known and generally accepted, usability engineering principles are rarely used in real-world software development projects. [8] [9] Basic principles such as early focus on the user, empirical measurement and iterative design are often overlooked or totally ignored in even in real-world product development.

Nielsen identifies perceived cost or "intimidation" as a main barrier for their application. [10] The iterative process and the adjustment of specifications to user requirements are bound to increase both time and monetary cost of the design process. While ultimately this should pay back in terms of preserved value to the user and increased commercial success of the final product, incorporating the same principles in the context of a capstone design, where both the time constrains as well as the lack of a financial motivation form major dis-incentives, faces major challenges. However, in the same report [10] Nielsen claims that using cost effective choices and solutions the cost may be justifiable.

Howard identifies an educational problem in user-centric design, namely a mismatch between the designers' perceived needs, which are governed by their knowledge of available tools, what they actually need, including tools they may or may not be aware of, and the knowledge of tools that curricula actually provide. [11] In this context, he suggests that identifying areas of resource / design mismatch as possible targets for educational programs that would deliver a good return on investment if addressed in curriculum design (Figure 1).

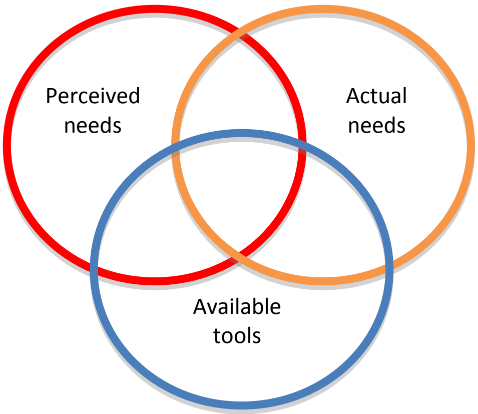

Figure 1. Venn diagram of knowledge perception during design (adapted from [6]).

Figure 1 implies that a major part of the design cost, in general, emanates from the designer being unaware of tools that are useful, or even necessary, to facilitate the design process. This is more true in the case of senior design capstone project, where the team's inexperience is bound to limit their knowledge of the actual needs; it is a common experience of the authors that *perceived needs*, especially regarding the main areas of lack of technical knowledge (e.g. mechanical engineering aspects of a robotics project for electrical engineering students) usually dominate students' efforts.

However, fostering user involvement in the design process is a so-called soft skill, which is easy to get overlooked in the context of the challenges of a senior design project. Therefore, in this project we decided to document and identify its main challenges, so to subsequently address them in curriculum development.

3. Methodology and Results

Four student teams, consisting of a total of 15 students, have completed the study to date. All students were seniors (fourth year students) of the Electrical Engineering, the Computer Engineering or the Bioengineering BSc Programs of George Mason University, and undertook this work as part of the requirements for the capstone design classes ECE 492 and ECE 493 Senior Advanced Design Project.

For the purposes of the capstone design class, students form teams that consist of 2-5 members, choose a topic, and they seek out a faculty advisor that is willing to sponsor their project over a period of two semesters. Throughout this period, the students work towards completion of the project. Criteria for successful completion include (1) demonstration of a working prototype solution to the original problem (2) documentation of the design process through series of reports and (3) oral presentations documenting the teams' progression towards that goal.

As part of this project, we introduced three additional components to the senior design project. The major one was the introduction of an external user, who was a member of the GMU community with disabilities. All senior designs discussed aimed at designing an assistive technology device tailored to the needs of the user, with the ultimate goal of the user getting the device at the end of the two semesters, and actually using it. The rationale behind this introduction was threefold: First, it would place the senior design process within the needs of an external user, increasing the accountability of the student team to produce a design within reasonable constrains and actually useful. Secondly, it would introduce the students to the process of user-centered design, by enforcing regular meetings between the user and the team so as to ensure that the design met the needs of the user. Lastly, the idea of actually enhancing the quality of life of the user through their device had an extra motivating effect on the students.

The second component was the introduction of an advisory team. The team consisted of the main faculty advisor, one or two faculty members that acted as secondary advisors, and an expert on assistive technology from the Office of Assistive Technology of the university. Students could arrange meetings with the advisory team on an ad-hoc basis, and the whole advisory team was present for the required midterm and final presentations of the projects. The reasoning for including a team instead of a single faculty advisor was to better support the students through the complexity of the projects.

The third component was a series of questionnaires that all involved parties (students, users, advisory team members) needed to fill out at given time points throughout the two semesters of the senior design process. The questionnaires aimed at gaining information about the design process, the communication between the user and the team, the level of involvement of all parties, and to identify problems in the process before they escalated. Design teams were asked to fill out a "formative" questionnaire per semester, as well as a "summative" questionnaire at the end of their senior design course; users and facilitators were asked to fill out questionnaires once per semester.

For this paper, we concentrate on the aspects of the questionnaire that regard the communication process between the team and the user. Specifically, the members of the design teams were asked:

- Rate your interaction with the person with disability in terms of feedback on the project (would you like the person to be more active / less active / why?)
- In terms of your design specifications / goals, what percentage would you say is directed by the user, what by the project facilitators, and what by your team?

Similarly, the users were asked at the end of the project to rate their interaction with the design team, and elaborate on whether they would like to change something in it.

Excessive politeness, as mainly evidenced in the difference of opinions on the rate of project success between project facilitators and project users, was our main problem with the responses in the questionnaires, which however still provided useful information. In the students' perception, a 53% of their specifications were influenced by the user; 32% by the design team and 15% by the advising faculty. Interestingly, in terms of interaction with the user, 65% of the responses were indicating that they would have liked a better interaction and more feedback from the user, with only one response indicating that user feedback could have been overwhelming in terms of complicating the project specifications. However, all students were appreciative of the user involvement, stating "that it helped a lot with their design".

Team responses indicate three phases in the team-user interaction. There is an initial peak at the beginning of the project (weeks 3-10), when the team and the user try to jointly put together the specifications of the desired product. This is followed by a phase of limited interaction (weeks 10-30), when the team concentrates on actually building the device, and is mostly absorbed in the technical challenges rather than the usability. Then, after the first prototype is constructed, teams enter the testing phase, where user interaction peaks again (weeks 30-34, but ideally earlier than that); however, this last period is subject to severe time constrains, especially if teams delay in delivering the prototype.

User responses to the questions were limited in number. While most users were very gracious in providing an assessment of the team, some complains did surface. These mainly concerned (a) an inability on their behalf to provide reasonable feedback until more work is performed, and (b) lack of effective communication.

4. Discussion

Based on our results, it seems that incorporating a user into the design process is of benefit to students in the context of a senior design capstone project. However, it is also obvious that there are problems with this interaction. Helping the students overcome these problems is not straightforward.

In our experience so far, students begin these projects with a great amount of enthusiasm. The prospect of helping a person with disabilities is a noble cause that acts as an extra motivator to the usual course requirements, and it is the authors' experience that students show increased motivation in the beginning. This is evident in initial meetings with the user, where the general project needs and specifications are discussed. During this phase, the team is tasked with coming up with proposed solutions, and to come to an agreement with the user as to which one to pursue, and how to formulate the specifications for it.

In the second phase of the senior design, the team needs to build a working prototype of their proposed solution. Two main problems arise during this time period: (a) the team is majorly preoccupied with the technical difficulties of their project, needing to invest significant time in learning new skills and trying out different solutions, and (b) the team realizes that some of the initial specifications may be, given the constrains, impossible to meet. Communication with the user seems to suffer during this time period, as the team directs its time resources towards addressing the technical problems, where they perceive user feedback not to be as valuable. This is in strong contrast to a usual senior design project, where the faculty advisor usually assumes also the role of the user: in this case, communication with the faculty advisor satisfies both the need for technical advice and design adjustment. In the external user case, consulting with just the faculty advisor does not substitute for consulting with the user. Communication at this point is more difficult, as evident by the first user comment ((a) above): it is difficult for a user with a non-technical background to provide feedback on an incomplete design, unless the team makes the effort to explain what these changes will really mean for the final design. However, it also crucial: in an extreme case, such modifications lead to the user immediately rejecting the first working prototype as being too bulky for his needs; the team needed to come up with a second design, which delayed them two months.

During the testing phase, user interaction peaks again, due to the need for user to provide feedback on the final design. The main caveats in this phase are time constrains: while at the beginning of the senior design process teams are made aware that they need to devote two months to testing, especially given that the availability of the user is going to be limited, this rarely happens, leading to some minor tension towards the end of the senior design process.

Based on our experience, it is vital for faculty advisors to support the students through the communication process with the end user. In our view, there are three main stages when the faculty advisor can help the team with this process:
In the *specification* stage, it is important for the advisor to help eliminate misunderstandings as to what may be technically feasible within a senior design. While this is part of the role of the faculty advisor in general as far as the specification process goes, it is important that there are no misunderstandings from the part of the user as well. In our experience, both parties are prone to overestimating what is feasible given time, budget, and levels of expertise of the senior design team. Therefore, a meeting at the specification stage with all stakeholders present may benefit the process.
In the *development phase*, it is important to help the team think through the impact of design decisions on the final product. It often the case that senior design teams, when focused with technical problems, opt for solutions that will produce a *working* device, but not a usable one. Communicating the impact of design choices to the user, along with their effect on specifications, is in our experience a necessary step in order to avoid surprises. Here, the advisor can help the team think through what that impact will be.
Lastly, there is no substitute for a project being on time and allowing for sufficient *testing* time, but this is often not the case. Here, our approach is to emphasize to the team that it is their responsibility to make it happen, and that, in order to make it happen, task management and effective lines of communication with a topic expert from the facilitator team is paramount.

5. Conclusion

User-centered design can be a rewarding experience in the context of senior capstone projects, both in terms of increased interest and in development of soft communication skills for the students involved. The active involvement of an external user is crucial in our case both for putting the design process into the perspective of a final product that needs to be usable, rather than just earning a passing grade, as well as for motivating the students by inserting a human relationship into it. This process however is not without additional stress and problems for the team. Our preliminary data suggest a relatively steady pattern of the emergence of these problems. This problem description suggests that active involvement of the faculty advisor may be beneficial in order to ensure that the communication of the students and the user is yielding the expected benefits.

We believe that in a user-centered senior design the role of the faculty advisor cannot be limited to that of a technical facilitator, but, based on our results, needs to expand to providing both organization and soft skill advising. For our future research, we will concentrate on ways to help the design team maximize the benefit from user meetings. We will ask the design teams to keep detailed logs of meetings with the user, and introduce a user meeting evaluation instrument, which will be used (a) before the meeting to state the goals for the interaction and (b) after each meeting to evaluate (i) the degree to which design specifications change after each meeting, and (ii) the degree of user satisfaction with the current progress. We believe that these instruments will help the teams realize the role of the user earlier in the design process and avoid surprises, misunderstandings or deceptions later in the project.

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