How can user-centered design help us think about the challenges of engineering education?

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Abstract
Because engineering education is a complex endeavor, tools that help educators understand engineering education can be valuable. User-centered design is a conceptual tool that educators can use to understand current projects and imagine new opportunities. This paper focuses on the concept of user-centered design and its application to engineering education.

Introduction
Educators interested in getting a better understanding of engineering education can draw upon a variety of perspectives (e.g., a systems perspective, a cognitive perspective, or a rhetorical perspective). User-centered design is a promising perspective for helping educators understand current projects and imagine new projects in engineering education.

UCD is a design philosophy built on three principles – early and continued focus on users, empirical measurement, and iterative design[1]. At the Laboratory for User-Centered Engineering Education (LUCEE), we have been exploring the use of user-centered design techniques in engineering education. We are interested in UCD because of the way it focuses attention on the design aspect of what is done in engineering education, the way it raises questions about the users of engineering education, and the way that it gives rise to ideas for both classroom practice and larger-scale projects.

In this paper, we discuss the idea of user-centered design and its application to projects in engineering education. We then describe two LUCEE projects through the lens of user-centered design—1) a series of research studies exploring what engineering students learn when building portfolios and 2) the design of a website to support engineering educators involving a study of the teaching challenges of engineering educators. In each description, we illustrate the link between the projects and the user-centered design approach. We close with reflections on the contributions and limitations of using user-centered design as a tool for engineering education.

Design and user-centered design
Designers change existing situations into preferred ones[2], by developing solutions that satisfy a wide variety of goals and constraints. From an engineering perspective, important design considerations include structural stability, maintenance costs, reliability, and environmental impact. Because most engineering systems involve users, it is important for engineers to also take user issues into account. User-centered design has emerged in response to products and

processes designed in ways that neglect important user considerations with results ranging from simple difficulties to serious errors and even death[3,4,5].

At its core, user-centered design is a philosophy that reminds designers to focus on the user. In this respect, user-centered design fits in with the “design for X” approach to design (e.g., design for maintenance, design for decommissioning). The goal of user-centered design is to develop products and processes that people find useful and usable[6,7]. Usability and usefulness are typically measured in terms of metrics such as task completion, number of errors, overall satisfaction, and perceptions of meaningfulness. The goal of user-centered design is not to suggest that other design factors are not important, but rather to remind designers of the critical importance of the user when users are involved.

User-centered design is also a design approach that focuses on three principles—early and continued focus on users, empirical measurement, and iterative design[1].

- Early and continued focus on users. The goal is to gather information about users that is important and relevant to designing products or processes for them. This includes information about what people are trying to do and how they do it, their mental models, and the resources they use in the environment. User-centered designers use a variety of techniques for gathering this type of information including contextual inquiry, ethnography, and interviewing[8,9,10].
- Empirical measurement. The goal is to remind designers to move beyond their ideas and suppositions about how users will interact with designs, and move toward the collection of data on how actual users do actual tasks with the product or process. The usability test or usability study is a core testing strategy for user-centered design. In a usability test, data is collected on the process of doing a task (time, errors, satisfaction) and the outcomes (how successful, satisfaction).
- Iterative design. The idea behind iterative design stems from the observation that it is difficult to predict how events will actually transpire when designing for users, and one of the best ways to truly understand what is best for a user is to have users interact with the design and see their reaction. As a result, it is important to build iteration into the design process.

Recently, ideas about user-centered design have been formalized through ISO standards[11]. The standards, which use the term human-centered design, suggest specific activities to do at specific points in the design process. The existence of such standards significantly underscores the emerging importance of considering user issues in the design process.

Applying user-centered design to engineering education

Applying the idea of user-centered design to engineering education requires addressing at least two questions: 1) who are the users? and 2) how do the three principles apply to situations in which these users are involved? This section addresses these questions in turn.

In the context of engineering education, students and educators represent two important user groups. Students use elements of the engineering education system such as curricula, learning experiences, educational technologies, office hours, and lectures in order to achieve goals such as graduation, professional preparation, and effective learning. Educators (faculty as well as teaching assistants) use classrooms, educational technologies, workshops on improving teaching, web resources that support teaching, and many other system artifacts in their efforts to teach effectively and efficiently, to increase their knowledge of teaching, and to accomplish other teaching-related goals.

A user-centered design perspective for helping either of these user groups entails early focus on users, empirical measurement, and iterative design. For example, a UCD perspective on designing for students would entail early focus on the needs, prior knowledge, attitudes, etc. of the students; empirical measurement of student use of the initial designs; and iteration on the designs based on the results of the empirical measurement. The process would be similar for efforts to support educators. In the next section, we describe two projects through this user-centered design lens.

Example project 1: Helping students integration knowledge through portfolio construction

The first example project focuses on students as users within the engineering education system. The project is part of a five-year grant funded by the National Science Foundation. The goal of the grant is to investigate how having students construct portfolios can impact, enable and support student efforts to integrate their engineering knowledge. The work of the grant is guided by three research questions:

1. What are the impacts of portfolio construction, particularly in the areas of knowledge integration and identity formation?
2. What are the mechanisms that lead to these impacts?
3. Under what conditions do these mechanisms result in an impact?

Here we describe one part of this grant, specifically an effort to develop a version of the portfolio construction activity appropriate for seniors in the department of Technical Communication at the University of Washington. We began our design process by gathering our accumulated knowledge about the user population (the students) from a number of venues. For example, from our own prior research on student understanding of their discipline and the research of others, we knew that students often have difficulty articulating a) a coherent sense of themselves as a professional, b) the dimensions of their profession, and c) examples of their own activity that provide evidence of accomplishments relative to these professional dimensions. From research others have done on the lives of undergraduate students and from our own work with students, we thought about the diversity of student backgrounds, the non-traditional backgrounds of many of the students, and the general pace and fractured quality of the lives of undergraduate students. We also used information about users that we had collected through prior studies of students building professional portfolios. In particular, we took into account lessons from a prior study of graduate students building teaching portfolios through an eight-week long program[12].

We then focused on designing the intervention – a version of portfolio construction consistent with our goals and the information we had about our users (the students). A core of the design effort was the specification of the type of portfolio students would be asked to build. We decided to have students work on an unstructured professional portfolio. In such portfolios, the portfolio consists of a collection of artifacts used to substantiate claims that someone is interested in making about him or herself as a professional (see Figure 1). In our work, we are interested in professional portfolios, in which the collection of artifacts is centered on and thematically organized by a professional statement. Claims made in the professional statement are used as criteria for choosing artifacts. Each chosen artifact is annotated to provide the context necessary for an audience member to understand its relative significance. Figure 2 shows the main page of one online professional portfolio.

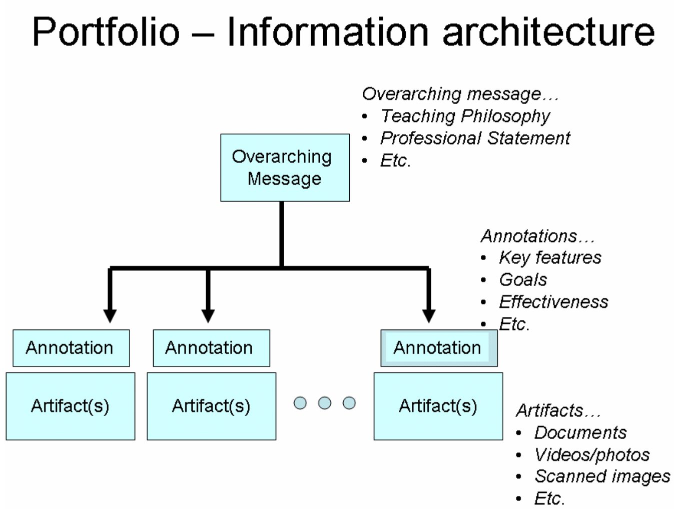

Figure 1. Information architecture of a professional portfolio

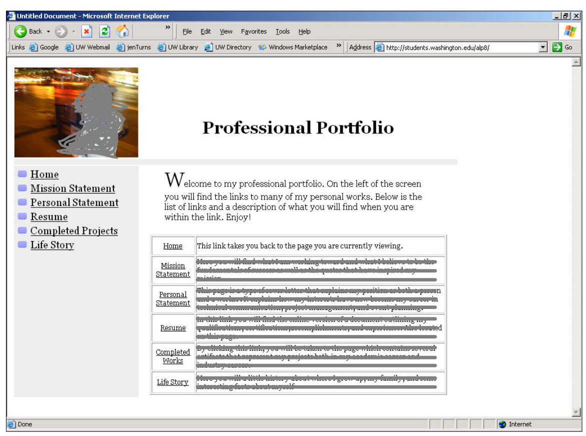

Figure 2. Main page of example online professional portfolio

In addition to specifying the type of portfolio to be constructed, we also specified the sequence of activities students would be asked to complete (i.e., the curriculum). We designed a quarter-long sequence of sessions through which the students generated the individual portfolio components, integrated the components into a coherent portfolio, got feedback on the portfolio from outside evaluators, revised the portfolio, and then presented it to the faculty of the department for grading. The sequence of sessions, specific activities within the sessions, and even the handouts that guided students through the sessions were designed with the user information in mind. We titled this program the Technical Communicator Professional Portfolio Program (TC3P).

To provide us with empirical data to inform iterative design, we made this pilot version of the program available to students as one way to complete their senior project requirement. In a department with around twenty students per undergraduate class, seven students initially signed up, and five completed the program. During the offering, we collected multiple types of data: observations during weekly sessions, final interviews with all participants, a focus group of all participants once the program ended, and final surveys from all participants. In our data analysis, we used a coding process to derive emergent themes from our data sources. The resulting findings allowed us to better understand the usability and effectiveness of the program.

In terms of iteration, we used the results of our empirical study to understand how to revise the program for the second offering. As a result, the second offering of the TC3P during winter 2005 showcased a number of changes including the construction of wireframe portfolios near the beginning of the course, more structured peer evaluations, guest speakers from industry, and a meeting space with better computer access.

Since the goals of our overarching grant are to explore the benefits of portfolio construction with a wide variety of undergraduate engineering students, we are currently looking to implement this refined design with students in more traditional engineering fields. We expect that the differences between these students and the students in technical communication will necessitate still other iterations on our design.

Example project 2: Supporting the teaching challenges of engineering faculty

The second example project focuses on educators as users within the engineering education system. This work is also supported by a grant from the National Science Foundation. The idea of the grant is to build a web-based resource for engineering educators based on research into the challenges that engineering educators face. While multiple websites have been developed to help engineering educators, little evidence exists confirming their effectiveness, while evaluation using inspection methods suggests that these websites have room for improvement[13].

The bulk of our work has constituted not only an early focus on users, but also a sustained and relatively unprecedented focus on users. To this end, we have been conducting a qualitative study of the teaching challenge and concerns of the engineering education community. The catalyst for the grant was a unique opportunity to work with an instructional consultant to understand, through her interactions with faculty, the challenges that engineering educators face. As a result, debriefing interviews form the core of our approach (for more information on the methodology for this work, please see Eliot and colleagues[14]). In these interviews, we debriefed the instructional consultant after actual consultations with individual faculty members and teaching-related groups. Maintaining the instructional consultant's client confidentiality policy has been a key consideration in the design of the study. In all, we will have conducted a total of 66 interviews with the instructional consultant. Our analysis of the data has focused on identification of specific teaching concerns and ways to aggregate these concerns.

Without a doubt, our user research has given us great insight into the teaching concerns of people within the engineering education community. For example, we have learned about educator concerns related to the writing of grants involving teaching issues, revising a department's curriculum, acculturating to a US university, mentoring graduate students, and developing more effective grading practices. We also learned about concerns associated with students, teaching assistants, deans, and department chairs.

What has been more surprising to us is the manner in which the concerns arise and are discussed with the instructional consultant. We initially imagined that clients would come to the consultation process with clearly defined questions that we could simply document and then translate into a website. What we found, however, were clients coming for discussions that were anchored more in situations than in questions, discussions that covered a broad range of concerns in a non-linear format, and an instructional consultant serving multiple roles (e.g., information source, confident, translator.)

Our focus on the users has caused iteration in the conceptual design of our proposed web site before even beginning to build the site and empirically measure use. In our original proposal, we proposed to build a website using an underlying question and answer structure, with the questions mined from our user research. Because of our discovery that engineering educators face complex situations that do not seem well described by a question-answer structure, we are currently moving away from question-answer website architecture and exploring the idea of a website where the information and resources are framed around a personal account of an archetypal educator—a persona. As we move forward with our web design, we will conduct empirical measurements (usability studies of prototypes and near-final web pages) in order to further iterate the design.

Contributions and limits of user-centered design

Thus far in this paper, we have described the concept of user-centered design, discussed its application to engineering education, and presented two projects that illustrate how a user-centered design perspective can be instantiated in educational projects.

Clearly, user-centered design is not the only way to approach projects in engineering education, or the specific projects we just presented. For example, engineering educators can think about engineering education from a systems perspective, a rhetorical perspective, instructional design perspective, cognitive perspective, or social-historical perspective; and aspects of the previous two projects could have been described from these perspectives. As the previous examples illustrate, however, it is also possible to describe these projects through a user-centered design lens. Below we speak to the value of such a perspective.

Earlier we mentioned that we are interested in user-centered design because of the way it focuses attention on the design aspect of what is done in engineering education, the way it raises questions about who are the users of engineering education, and the way that it gives rise to ideas for both classroom practice and larger scale projects. The previous two examples illustrate how this design perspective can be used to characterize projects in engineering education, and we hope these examples have stimulated ideas for still other projects. As a part of each project, we asked questions that were clearly driven by our user-centered perspective – questions about usability of the portfolio instructional materials and questions about the teaching concerns of engineering educators.

Upon reflection, we also believe that user-centered design can offer the following benefits to a designer working in engineering education. A user-centered design perspective…

- highlights a distinction between much of engineering design (without people) and education related work in which human activity is central.

- provides a design model for engineering teaching that may be more helpful for engineering educators trained in engineering design.
- provides one way of organizing information that is already out there, such as information already available on the "users" and information about what contributes to the "usability" of specific designs.
- suggests relevant questions to ask during the design process, such as the questions, "What do we need to know about the user?", and "How will we evaluate this from the user perspective?"
- helps designer/educators see something familiar (their teaching situations) in a new light.

That being said, we already see a move toward user-centered approaches in engineering education. There is an increasing amount of work being done to simply characterize engineering students (e.g., work on student conceptions/misconceptions, skills and knowledge[15]; a recently begun longitudinal study of the engineering student learning experience), and an emergence of work on characterizing the educators themselves (e.g., a needs analysis conducted recently at the University of Wisconsin). Moreover, iteration and even empirical measurement (in the form of pilot studies and formative evaluation) already seem like common aspects of work in engineering education. For example, educators often modify courses from offering to offering as they gain insight on the usability and effectiveness of their instructional design. Still further, efforts to empirically measure what happens with education-related designs are benefiting from work on assessment tools, web-based instructional tools that collect data on their own use, and other techniques. We look forward to seeing these trends continue and to contributing to an ongoing conversation about how to most effectively approach the design of products and systems that educators and students use to most effectively support the goals of engineering education.

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