Undergraduate Conceptions of the Engineering Design Process: Assessing the Impact of a Human-Centered Design Course

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Abstract

Throughout their education, engineering design students not only learn the design process, but also form and refine their conception of engineering design. Building on the results from a study of practicing engineers' conceptions of design, we present survey results from engineering students enrolled in Mechanical Engineering 110 (n=51), an upper-division human-centered design course. We compare the students' initial conceptions of design from before the course to those after the course. In particular, we look at how the course affects their perceived importance of specific design skills, and their level of agreement with a series of statements on the nature of design. We also compare the students' conceptions of design after the course to those of practicing engineers from a previous study. The upper division engineering students showed a remarkable similarity to the results of the practicing engineers with a few notable exceptions. Our results show that after the class, more engineering students identified synthesis as among the more important skills, and brainstorming as among the less important skills than before the class. Although the upper division engineering students before the course agreed with the practicing engineers in the idea that design is solution-led, this perception changed after taking the human-centered design course which emphasizes the importance of user research in the design process.

Introduction

The role of engineering design educators is to guide engineering students in the development of their conceptions of engineering design and the design process. These conceptions of design connect to each designer's Design Identity, "sets of beliefs, attitudes, and values about design"[1]. This can include how a designer defines characteristics of good design, the design process, designers' responsibility, the role of evaluation in design, and how that identity views and interprets alternate perspectives[1]. These perspectives on engineering practice ultimately play a role in critical collaborative practices, such as shared understanding[2,3,4] and team conflict[1].

There are several different ways to describe varying conceptions or approaches to design. In Sanders' map of design research[5,6] (Figure 1), the horizontal axis "describes the mindsets of those who practice and teach design research," identifying "two distinct cultures of design research," while the vertical axis indicates how designers go about the process of design, either as a Design-Led process or a Research-Led process. Fallman[7] describes three different perspectives on design: conservative, pragmatic, and romantic. Each of these perspectives is described by influences from different disciplines, and the philosophical mindset behind each approach.

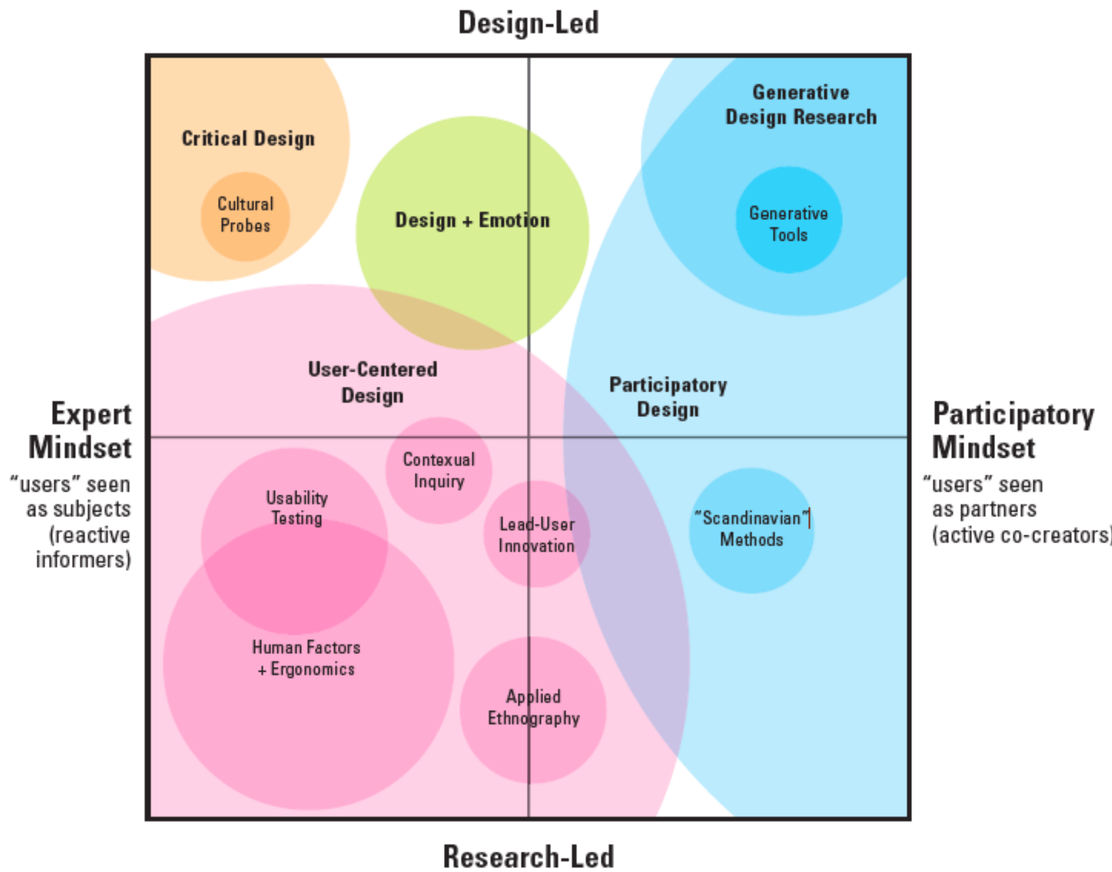

Figure 1: Sanders' map of design research[5,6], with the "Design-Led / Research-Led" axis and the "Expert Mindset / Participatory Mindset" axis.

Mosborg et al.'s studied the conceptions of design of practicing engineers[8] by surveying and interviewing 19 advanced practicing professionals from a range of engineering disciplines (mechanical, electrical, civil, industrial, materials science, systems engineers) about their conception of design and design processes. In this study, the researchers asked the engineers to "create a picture or representation of what you think the process of design is." They also asked the practicing engineers to rate the six most and least important skills from a list of 23 skills. Finally, they asked the practicing engineers to rate on a 5-point Likert scale the extent to which they agreed to 27 statements about design. While these results provide a point of comparison for this study, it is important to note that these results are for a wide sampling engineers, and not necessarily design engineers.

Lande & Leifer[9] studied student perceptions of design by surveying 30 students in a graduate-level mechanical engineering design course. In addition to collecting concept maps of the design process, they asked the students to "Draw an Engineer" and "Draw a Designer", similar to previous "Draw an Engineer"[10] or "Draw a Scientist" test[11]. This qualitative study illustrated some of the conceptual differences between the roles of engineering and design.

In this study, we aim to improve our understanding of what students' conceptions of design are, how a course on human-centered design might affect those conceptions, and how these student conceptions compare to those of practicing engineers.

Research Test Bed and Methods

We surveyed 51 undergraduate students in Mechanical Engineering 110 (ME110), "Introduction to Product Development." ME110 is an upper-division undergraduate elective course on human-centered design at the University of California, Berkeley. As ME110 is a project-based elective course, students self-selected to participate in a human-centered engineering design project. Throughout the course, students work in teams to complete a semester-long design project. The course was open to students from all disciplines; while most students came from Mechanical Engineering, the course also attracted a few students from additional engineering disciplines as well as business and the humanities.

The survey uses the survey from Mosborg et al.[8] (see Appendix A). In the survey we asked students to identify the six most and six least important skills from a list of 24 design skills, to which "Understanding Others' Point of View" was added to the original Mosborg list due to its importance during the needfinding in Human-Centered Design. We also asked the students to indicate the extent to which they agree with a series of 23 statements on design. This list of statements relate to the designer's goals, the design process, the nature of design activity, what makes a good designer, etc.

Of all the students in the course, 51 completed the survey both before and after the course. Of the students who completed both surveys, 47 were engineers and 4 were non-engineers. Due to the small number of non-engineering students, no statistically significant results could be found comparing the non-engineers to the engineering students. For our analysis, we will focus on the results from the engineering students. We will compare the engineering students' conceptions from before the class with those afterwards, and the engineering students' responses after the course with the practicing engineers' responses from Mosborg et al.[8].

Results: Before & After ME110

To look at whether or not students' conceptions of design changed over the course of ME110, we compared their survey responses from before and after the course.

Most/Least Important Skills

Figure 2 shows the number of students that marked each skill as "Most Important" both before and after the course. We used a two-sample Student's t-test to compare the percentages of students who listed a given skill as "Most Important" before and after the course. Only "Synthesizing" (before= 2%; after= 25%) had a statistically significant difference in percentages ($p=0.0005$).

Figure 3 shows the number of students that marked each skill as "Least Important" both before and after the course. We used a two-sample Student's t-test to compare the percentages of students who listed a given skill as "Least Important" before and after the course. Of all the skills, only “Brainstorming” (before= 0%; after= 16%) had a statistically significant difference in percentages (p=0.0033).

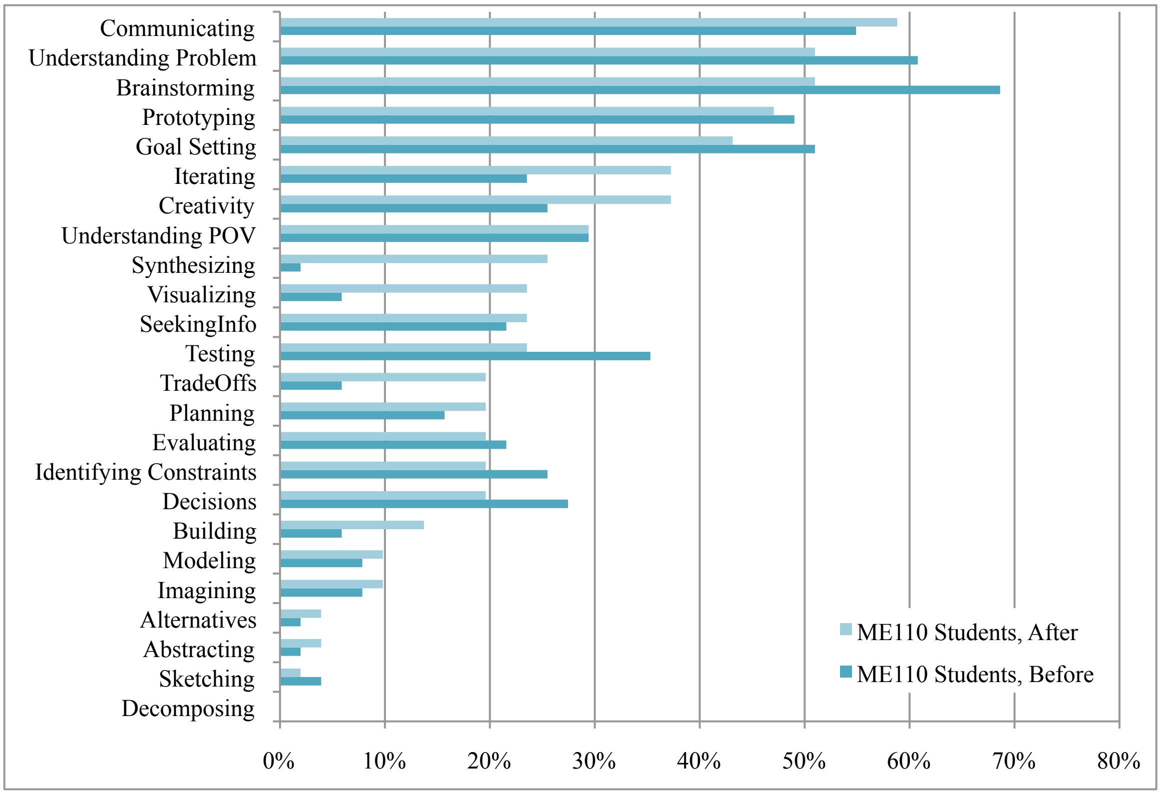

Figure 2: Percent of ME110 students' selecting design skills as "Most Important", before and after the course.

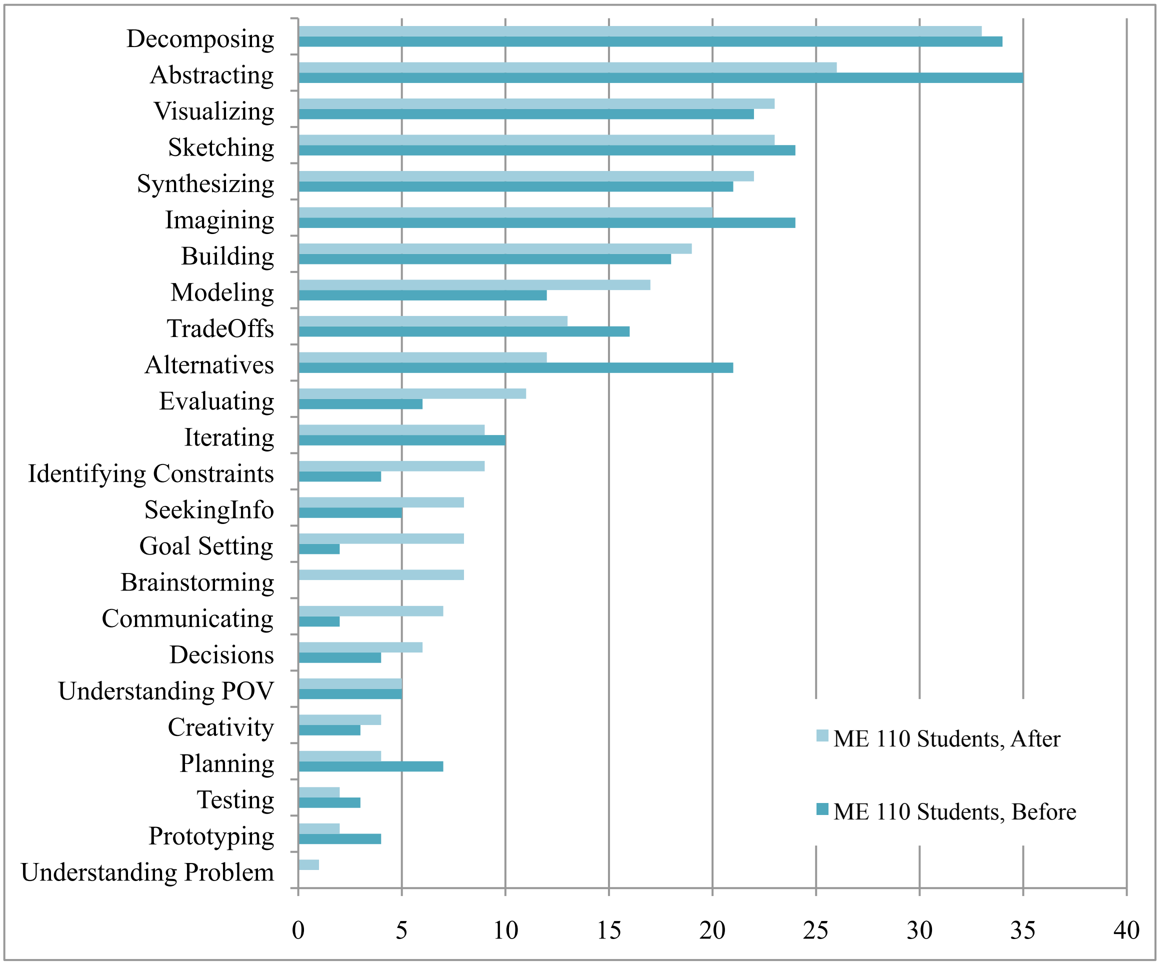

Figure 3: Percent of ME110 students' selecting design skills as "Least Important", before and after the course.

Statements on Design

We compared the ME110 students' responses to the 23 statements on design before and after the course. Table 1 lists the students' mean results from before and after the course. We tested the significance in the change of opinion by conducting a two-tailed, paired t-test. The statement with a statistically significant change was "Design is often solution-led, in that early on the designer proposes solutions in order to better understand the problem" (before=3.53; after=2.9; $p = 0.0023$). Initially, the students mildly agreed with the statement that the design is solution-led. The ME110 course, however, focused heavily on questioning the design problem and conducting user research before leaping into a solution.

	Before, Eng Mean	StDev	After, Eng Mean	StDev
In design, a primary consideration throughout the process is addressing the question "Who will be using this product?"	4.51	0.50	4.36	0.67
Information is central to designing.	4.19	0.68	4.36	0.70
Design, in itself, is a learning activity where a designer continuously refines and expands their knowledge of design.	4.17	0.60	4.19	0.74
Design is iteration.	4.12	0.86	4.43	0.83
Design is a communicative act directed towards the planning and shaping of human experience. The task of the designer is to conceive, plan, and construct artifacts that are appropriate to human situations, drawing knowledge and ideas from all the arts and sciences.	4.04	0.75	4.13	0.64
Designers use visual representations as a means of reasoning that gives rise to ideas and helps bring about the creation of form in design.	4.00	0.59	3.87	0.77
Creativity is integral to design, and in every design project creativity can be found.	4.02	0.89	4.17	0.73
In design, the problem and the solution co-evolve, where an advance in the solution leads to a new understanding of the problem, and a new understanding of the problem leads to a 'surprise' that drives the originality streak in a design project.	4.08	0.58	4.04	0.83
Design begins with the identification of a need and ends with a product or system in the hands of a user.	4.51	0.97	3.93	0.89
Design is as much a matter of finding problems as it is of solving them.	3.87	0.87	3.95	0.80
Design is "world" creation; everyone engages in design all the time. It is the oldest form of human inquiry giving rise to everything from cosmologies to tools.	3.85	0.83	3.87	0.82
A critical consideration for design is developing products, services, and systems that take account of eco-design principles such as use of green materials, design for dismantling, and increased energy efficiency.	3.85	0.83	3.97	0.79
Design is not a description of what is, it is the exploration of what might be.	3.77	0.78	4.00	0.75
In design it is often not possible to say which bit of the problem is solved by which bit of the solution. One element of a design is likely to solve simultaneously more than one part of the problem.	3.68	0.75	3.89	0.89
Visual representations are primarily used to communicate the final design to a teammate or the client.	3.74	0.87	3.51	1.12
Design is a goal-oriented, constrained, decision-making activity.	3.59	1.05	3.57	1.11
* Design is often solution-led, in that early on the designer proposes solutions in order to better understand the problem.	3.53*	0.99	2.91*	1.21
Designers operate within a context, which depends on the designer's perception of the context.	3.55	0.77	3.68	0.75
Design is a highly complex and sophisticated skill. It is not a mystical ability given only to those with deep, profound powers.	3.43	1.19	3.91	0.95
Good designers have intrinsic design ability	3.43	0.80	3.32	0.78
Designing is a conversation with the materials of a situation.	3.31	0.89	3.64	0.79
Design is primarily concerned with synthesis rather than the analysis.	2.47	0.97	2.64	0.82
Good designers get it right the first time	1.80	0.85	1.87	0.85

Table 1: Students' endorsements of design statements, before and after the course (n=51). Significant results are marked with an asterisk.

Results: Engineering Students & Practicing Engineers

We additionally looked at how conceptions of design differed between the students coming out of ME110 and their practicing peers that they are about to join. For this we compared the results from the survey after ME110 to the results published in Mosborg at al.[8].

Most/Least Important Skills

To compare the engineering students after ME110 with the practicing engineers, we conducted a two-tailed t-test comparing the percentages of people who included a given skill in their 6 most important or least important skills.

Figure 4 shows all results for the most important skills among the ME110 engineers after the course, comparing each with Mosborg et al.[8]. Of the skills, the difference between the practicing and student engineers' ratings of "Sketching" (practicing engineers = 53%; engineering students = 2%; p = 0.00006), "Identifying Constraints" (practicing engineers = 68%; engineering students = 20%; p = 0.00017), and "Goal Setting" (practicing engineers = 11%; engineering students = 43%; p=0.0017) were statistically significant.

It could be that the nature of the students' work is still different from practicing engineers' experiences in industry. Practicing engineers may use sketching as an everyday communication tool more than the students do. This could also be a reflection of age differences as well, with practicing engineers more likely to have had more emphasis in hand sketching in their undergraduate curricula in contrast to curricula today. Also, the engineering students in the class were challenged to find their problems in addition to solving them; as a result, they were setting their own goals instead of looking to other coworkers in management positions to help in goal setting.

Figure 5 compares the percentage of respondents that listed each skill as among the 6 least important, comparing the ME110 students after the course to the practicing engineers surveyed in Mosborg et al.[8]. Of the skills, the difference between the practicing engineers' and student engineers' ratings of "Evaluating" (practicing engineers = 0% ; student engineers = 22%; p = 0.000467) and "Building" (practicing engineers = 68%; student engineers = 37%; p = 0.00249) were statistically significant.

Student engineers in ME110 were not required to do as much engineering analysis, as a result they did not value evaluating as much in the context of their design project. The practicing engineers may have indicated building as one of the least important skills more than the engineering students because they may have coworkers who are prototyping specialists who assist with building separate from the design process itself.

Statements on Design

We were able to compare the students' endorsement of design statements with 13 of the published results of practicing engineers' endorsements from Mosborg et al.[8]. Table 2 includes a list of results from the ME110 students' final ratings of the statements on design along with the professional engineers' responses from Mosborg et al.[8].

In a two-sample t-test, there was a significant difference in “Design is often solution-led, in that early on the designer proposes solutions in order to better understand the problem.” (practicing engineers = 2.9; engineering students = 3.9; $p = 0.0004$).

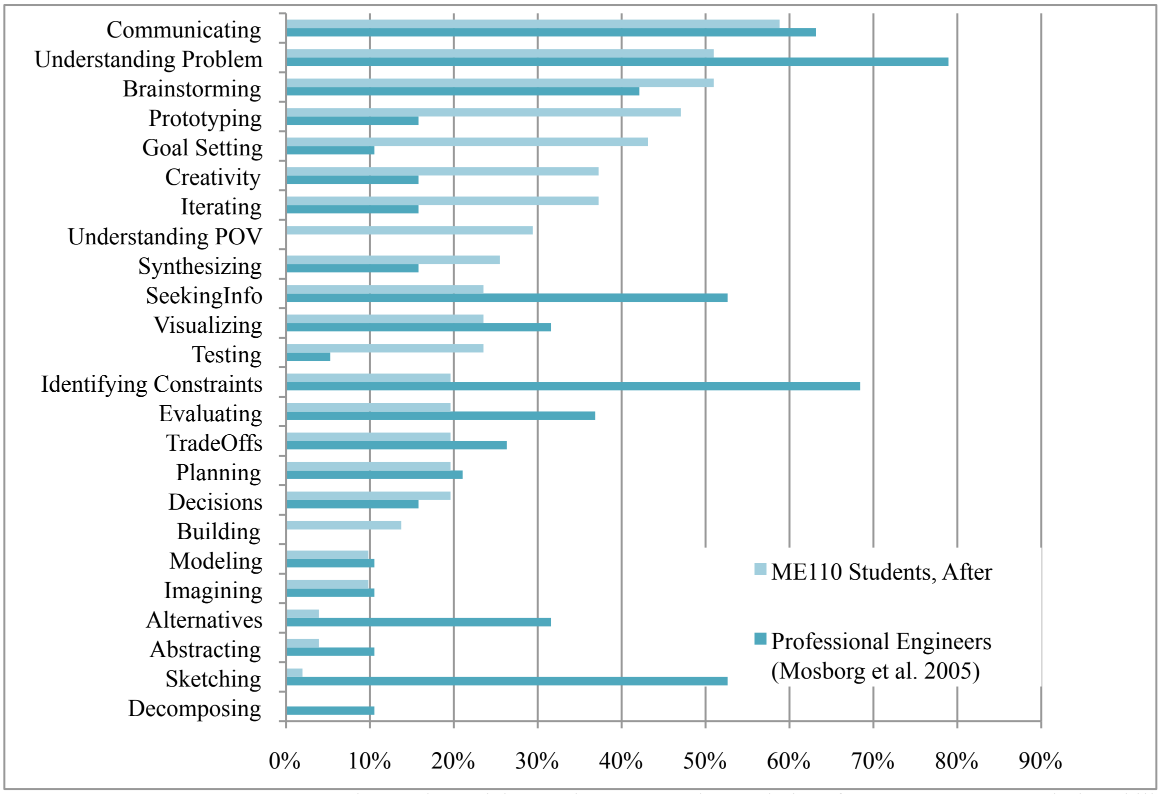

Figure 4: Percentage of ME 110 student and practicing engineer respondents’ choices for “Most Important” design skills.

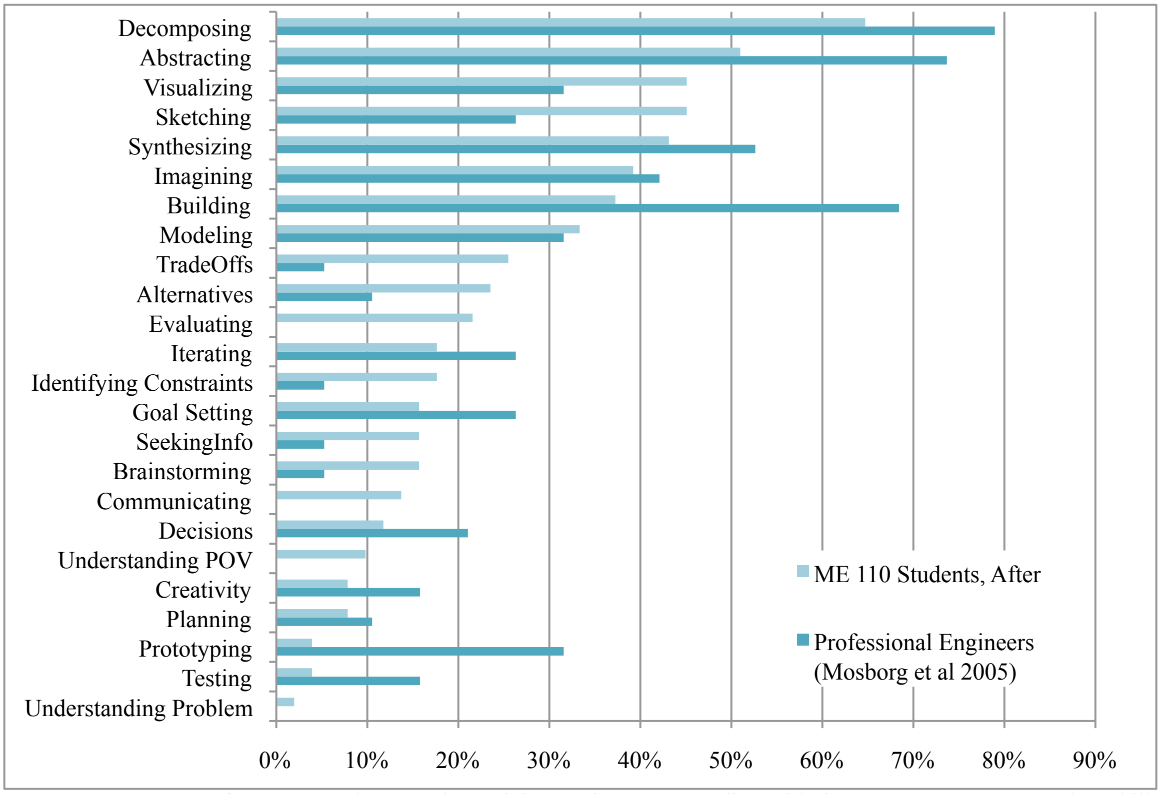

Figure 5: Percentage of ME 110 students' and Practicing engineers responding with the "Least Important" Design Skills.

	ME110 Students, After		Practicing Engineers Mosborg et al. (2005)		
	Mean	StDev	Mean	StDev	Median
In design, a primary consideration throughout the process is addressing the question "Who will be using this product?"	4.35	0.7	4.5	0.6	5
Information is central to designing.	4.3	0.7	4.4	0.8	5
Design, in itself, is a learning activity where a designer continuously refines and expands their knowledge of design.	4.2	0.7	4.3	0.8	5
Design is iteration.	4.5	0.8	4.2	0.8	4
Designers use visual representations as a means of reasoning that gives rise to ideas and helps bring about the creation of form in design.	3.9	0.8	4.1	0.7	4
In design, the problem and the solution co-evolve, where an advance in the solution leads to a new understanding of the problem, and a new understanding of the problem leads to a 'surprise' that drives the originality streak in a design project.	4.0	0.9	4.2	0.8	4
Design is as much a matter of finding problems as it is of solving them.	4.0	0.8	4.0	1.0	4
A critical consideration for design is developing products, services, and systems that take account of eco-design principles such as use of green materials, design for dismantling, and increased energy efficiency.	3.9	0.8	3.7	0.6	4
Design is not a description of what is, it is the exploration of what might be.	3.9	0.8	4.2	0.5	4
In design it is often not possible to say which bit of the problem is solved by which bit of the solution. One element of a design is likely to solve simultaneously more than one part of the problem.	3.8	0.9	3.8	0.9	4
* Design is often solution-led, in that early on the designer proposes solutions in order to better understand the problem.	2.9*	1.1	3.9*	0.7	4
Design is a highly complex and sophisticated skill. It is not a mystical ability given only to those with deep, profound powers.	3.9	0.9	4.0	0.6	4
Good designers get it right the first time	1.8	0.8	2.1	1.0	2

Table 2: Attitudes towards statements on design, comparing ME110 students after the course with practicing engineers from Mosborg et al. (2005). Statistically significant results are marked with an asterisk.

In Sanders' map of design research[5,6] (see Figure 1), one of the axes is whether or not the design process is Design-led (such as critical design approaches) or Research-led (such as human-centered or participatory design approaches). The "Design is often solution-led" statement is indicative of a design-led approach, similar to critical design. The practicing engineers' endorsement of this approach is indicative of how problems are often approached, while the ME110 students were encouraged to take a research-led approach throughout the semester. It is particularly interesting to note that there was also a significant different between the before/after case for the students for this statement – the students started out agreeing more with the professionals, but as they went through the course reconsidered their position. Another indicator of this shift can be viewed from the open-ended addition that our students added to the list of relevant skills for designers. There were nine comments associated with engaging with users and needfinding research. Some of these comments were general user research (*Identifying a need/problem, Market sizing*) while others were more specific to skills that are important in needs gathering (*Listening, Observing, Asking questions*), interpreting (*Empathy*), and communicating research findings (*Storytelling*).

Discussion & Implications for Design Education

The most notable finding is the similarity between the students post-survey and the practicing engineers, indicating that our engineering students are graduating with a professional view of engineering design and the design process. However, there were some interesting differences in a few aspects of the students' perspectives on design. Practicing engineers' particular conception of design is not necessarily the "correct" conception of design to which engineering students need to conform. The wide variety of problems that engineers and designers address may also require a wide variety of design approaches.

However, students and educators may benefit from acknowledging and exploring some of these different conceptions in order to have a better appreciation for what an engineering mindset looks like, particularly when collaborating with multiple disciplines who may have different ideas of what a design process should look like.

As educators of human-centered design, it is also important for us to consider what makes a human-centered approach different from other approaches, to draw contrasts and better communicate the approach to students. Sanders[5,6] describes user-centered designers as "us(ing) research-led approaches with an expert mind-set to collect, analyze, and interpret data in order to develop specifications or principles to guide or inform the design and development of products and services". Human-centered design seems to resonate most with Fallman's pragmatic account[7], partially because of its emphasis on contextually-relevant designs, as well as the disciplinary role models in bricolage, human sciences, and sociology.

Conclusion

This study looked at conceptions of design among engineering students participating in a upper-division human-centered design course. While the course itself did not drastically change the students' views of design, it did push them to think about design as research-led instead of solution-led.

Future work includes:

- *Institutional identity*: gather data from academics in an engineering department to compare with students' perceptions. Compare results from faculty at different educational institutions to look at varying perspectives between universities.
- *Broader development of engineers' conceptions of design*: gather data from entry-level and lower-division students' conceptions of design. This could lead to a better picture of how these conceptions develop over engineering students' professional training.
- *Multidisciplinary Conceptions of Design*: compare engineers' conceptions of design with their non-engineering collaborators.
- *Include additional questions* to examine the relationship between the designer and the user, to identify additional design perspectives from Fallman[7] and Sanders[5,6].

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Appendix A: Questionnaire

Of the design activities below, please put a check mark next to the six MOST important.

Abstracting	Goal Setting	Planning	Understanding the Problem
Brainstorming	Identifying Constraints	Prototyping	Understanding Others' Point of View
Building	Imagining	Seeking Information	Using Creativity
Communicating	Iterating	Sketching	Visualizing
Decomposing	Making Decisions	Synthesizing	
Evaluating	Making Trade-offs	Testing	
Generating Alternatives	Modeling		

Of the design activities below, please put a check mark next to the six LEAST important.

Abstracting	Goal Setting	Planning	Understanding the Problem
Brainstorming	Identifying Constraints	Prototyping	Understanding Others' Point of View
Building	Imagining	Seeking Information	Using Creativity
Communicating	Iterating	Sketching	Visualizing
Decomposing	Making Decisions	Synthesizing	
Evaluating	Making Trade-offs	Testing	
Generating Alternatives	Modeling		

Please list any relevant skills for designers that you could not find above.

Below are a number of statements people have made about design. We expect that different standards will appeal to different people. In the list below, please indicate the extent to which you agree with the statement provided. (Likert 1-5)

Good designers get it right the first time

Good designers have intrinsic design ability

In design, a primary consideration throughout the process is addressing the question "Who will be using this product?"

Visual representations are primarily used to communicate the final design to a teammate or the client.

Design begins with the identification of a need and ends with a product or system in the hands of a user.

Design is primarily concerned with synthesis rather than the analysis.

Design is a communicative act directed towards the planning and shaping of human experience. The task of the designer is to conceive, plan, and construct artifacts that are appropriate to human situations, drawing knowledge and ideas from all the arts and sciences.

Design is as much a matter of finding problems as it is of solving them.

In design it is often not possible to say which bit of the problem is solved by which bit of the solution. One element of a design is likely to solve simultaneously more than one part of the problem.

Design is a highly complex and sophisticated skill. It is not a mystical ability given only to those with deep, profound powers.

Designing is a conversation with the materials of a situation.

Design is not a description of what is, it is the exploration of what might be.

Design is often solution-led, in that early on the designer proposes solutions in order to better understand the problem.

In design, the problem and the solution co-evolve, where an advance in the solution leads to a new understanding of the problem, and a new understanding of the problem leads to a 'surprise' that drives the originality streak in a design project.

Design is a goal-oriented, constrained, decision-making activity.

Designers operate within a context that depends on the designer's perception of the context.

Creativity is integral to design, and in every design project creativity can be found.

A critical consideration for design is developing products, services, and systems that take account of eco-design principles such as use of green materials, design for dismantling, and increased energy efficiency.

Design is "world" creation; everyone engages in design all the time. It is the oldest form of human inquiry giving rise to everything from cosmologies to tools.

Design, in itself, is a learning activity where a designer continuously refines and expands their knowledge of design.

Designers use visual representations as a means of reasoning that gives rise to ideas and helps bring about the creation of form in design.

Information is central to designing.

Design is iterative.