**Teaching and Evaluating Design Competencies in the 21st Century**

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In 2004, the National Academy of Engineering published Phase I of the "Engineer of 2020" study, a project that engaged a diverse group of thought and opinion leaders to gather facts, forecast future conditions, and develop potential scenarios for the engineer in the year 2020 [1]. The next year, Phase II of the study identified several key attributes of the Engineer of 2020 [2]: possess strong analytical skills; exhibit practical ingenuity; possess creativity; good communication skills with multiple stakeholders; business and management skills; leadership abilities; high ethical standards; a strong sense of professionalism; dynamic, agile, resilient, and flexible; and lifelong learners. These attributes, including the need for engineers to bring their strong disciplinary analytical skills to a multidisciplinary team, are critical for design competency in the 21st century. The Engineer of 2020 attributes are inherently transdisciplinary and notably not specific to engineering. Similarly, design transcends disciplinary bounds, and brings together engineering, business, social sciences, and creative practices. In this paper, we study the growth of competencies taught in a graduate level human-centered design course. We use data collected from this course to provide an example of how we chose to teach and evaluate design competencies, which are intimately tied to the competencies of the Engineer of 2020.

## 1. Methods and Data

To increase the design competencies of graduate engineering students, ME 250 (course number changed) was created to use human-centered design methods to provide students hands-on real-world experience in developing innovative and customer-driven solutions. The course aimed to support students in building competencies in various dimensions of "design" and used *theDesignExchange*, a web portal of over 300 design methods aiming to provide design education tools for both academia and industry, as a framework for structuring the course in five design categories: Design Research, Analyzing and Synthesizing, Ideating, Prototyping and Building, and Communicating [3]. We gave students online surveys and conducted in-class activities at multiple points during the semester to assess the students' self-perception of their design competencies and their valuation of specific design skills. In the valuation of specific design skills we considered a subset of these competencies, the 34 "basic skills," first presented in our previous work [4]. These basic skills are those skills that are commonly used in human-centered design (e.g., Decision Making, Observing, Storytelling, Reframing), as evident by the skills needed to carry out human-centered design methods [4]. We present a summary of our research questions and methods in Table 1 below.

**Table 1**. Research questions and methods pursued in this study

| **Research Question** | **Research Tool** | **Scale of Research Tool** | **Time Point** |
|---|---|---|---|
| How did the students' self-perception of their competencies change during the course? | Collection of surveys to evaluate competencies in each design dimension: Overall Design, Design Research, Analyzing and Synthesizing, Ideating, Prototyping and Building, and Communicating. | Likert scale asking students to rank their confidence in their design competencies.<br>1 = "not confident at all", 5 = "very confident" | During the Semester and End of Semester |
| How did the students *think* their competencies changed during the course? | End-of-semester survey to evaluate how students felt their competencies in each design dimension changed during the course of the semester | Likert-type scale asking students how their competencies at the end of the course compared to the beginning of the course.<br>-2 = "much less", +2 = "much more". | End of Semester |

| | | | |
|---|---|---|---|
| How did the students' valuation of design competencies change during the course? | Two "competency sorting" exercises of 32 basic design skills (a notion introduced in our previous work [4]) | 2x2 diagram. "Skills I don't have" vs. "Skills I do have" and "Skills I don't want to hone more" vs. "Skills I do want to hone more" | Beginning and End of Semester |

Of the 58 students enrolled in the course, 52 completed all of the surveys and exercises presented in this paper. The course was comprised primarily of graduate mechanical engineers (ME), and our dataset includes 39 ME "Master of Engineering" students, seven ME MS students, two ME PhD students, one Electrical Engineering and Computer Science MS student, one Integrative Biology PhD student, and two undergraduate students (Computer Science and ME). Seventeen students are female and 35 are male.

**2. Research Findings**

We asked, in our initial and final surveys, "How confident are you in your ____ skills and abilities?" with each of the rows in Table 2 below filling in the blank. The responses to these questions are in columns 2 and 3. We also asked "How does your confidence level in your ____ skills and abilities now compare to your confidence level at the beginning of the class?" The responses to these questions are in column 5.

**Table 2**. Confidence ratings among six dimensions of design competencies

| | **Average Initial Confidence Rating** | **Average Final Confidence Rating** | **Absolute Change in Confidence Rating** | **Perceived Change in Confidence Rating** |
|---|---|---|---|---|
| **General Design** | 3.60 | 4.27 | 0.67 ** | 1.29 ^^ |
| **Design Research** | 3.35 | 4.17 | 0.83 ** | 1.21 ^^ |
| **Analysis and Synthesis** | 3.79 | 3.98 | 0.19 | 0.96 ^^ |
| **Concept Generation** | 3.40 | 4.15 | 0.75 ** | 1.10 ^^ |
| **Prototyping and Building** | 3.67 | 4.08 | 0.40 ** | 0.83 ^^ |
| **Visualization and Communication** | 3.77 | 3.90 | 0.13 | 0.94 ^^ |

Two-sample paired t-test ($H_0$: $\mu_{\text{final}} - \mu_{\text{initial}} = 0$) ** - significant at $p < 0.001$
One sample t-test ($H_0$: $\mu_{\text{perceived change}} = 0$) ^^ - significant at $p < 0.001$

We found that students on average became statistically more confident in their skills, a finding that held true for General Design, Design Research, Ideating, and Prototyping and Building. In all these dimensions, the majority of students had a positive change in confidence over the course of the semester. The most notable "absolute" confidence gains (column 4 equals column 3 minus column 2) were in Design Research and Concept Generation. Students did not become statistically more confident in their skills in Analysis and Synthesis or and Visualization and Communication, although the students had a high confidence in both these areas at the start of the semester.

The most notable "perceived" confidence gains (column 5) were in General Design, Design Research, and Concept Generation. The least notable gain was in Prototyping and Building. All of these gains were statistically significant. How students rated themselves on an absolute scale (i.e., 1 to 5, not confident to confident) and how they rated themselves on a relative scale (e.g., -2 to +2, much less confident to much more confident) are notable areas of further inquiry. We did not attempt to understand why students believed they improved more or less than they rated themselves to have improved, but this could be an area of future study.

We also see several patterns in how students valued specific design skills. At the beginning of the semester, the top three skills students wanted to hone more were *Identifying key insights* (45 students), and a tie between *Decision making, Digging deep, Pivoting,* and *Representing ideas visually* (44 apiece). The top three skills students felt that they already had were *Observing* (39 students), *Defining the problem* (38), and *Identifying obstacles* (38). The top three skills students did not want to hone more were *Working under time pressure* (29), *Record-keeping* (26), and *Delegation* (25). The top three skills students did not feel they already had were *Pivoting* (34), *Critiquing* (30), and

*Story building* (29). At the end of the semester, the top three skills students wanted to continue to hone were *Abductive reasoning* (47), *Critiquing* (45), and *Persuading* (45). Interestingly, none of the skills students identified in the beginning of the semester as wanting to hone more were still skills they wanted to continue to hone at the end of the semester. The top three skills students felt that they had at the end of the semester were *Observing* (42), *Working under time pressure* (42), and *Decision making* (41). The top three skills students did not want to hone more were *Mentoring* (25), *Identifying known and unknown* (24), and *Record-keeping* (23). The top three skills students did not feel they had at the end of the semester were *Drawing* (28), *Mentoring* (25), and *Pivoting* (25).

**3. Implications for Engineering Education**

Our work extends the previous work done by other researchers, as we take a deep view into one aspect of educating the Engineer of 2020: teaching and evaluating design competencies. Palmer et al. [5] focused specifically on educational structures and features that allow students to gain "contextual competence" (one of the skills identified in The Engineer of 2020 report). Based on both quantitative and qualitative research approaches, they found that students' contextual competence is influenced by their institution: characteristics (on a broad, university-wide scale), curriculum (including the courses offered to students), co-curriculum ("out-of-class" opportunities), professional practice opportunities, and connections to industry. These factors all strongly contributed to students' understanding of how their work is connected to a broader contextual understanding of the world, a skill crucial to the Engineer of 2020. Zoltowski et al. [6] found seven qualitatively different ways that student designers experienced and understood human-centered design. They posited that "becoming human-centered does not result from simply learning more about design or developing disciplinary skills," and that educating students in human-centered design requires a deeper component focusing on understanding the user. Knight [7] explored the "suite" of skills that the Engineer of 2020 must possess, focusing specifically on how the necessary competencies interact with each other. He used self-reported survey data and found six clusters of engineering students (marked by differences in their achievement in "fundamental skills", "design/contextual awareness", "interdisciplinary competence", and "professional skills"). One of these six clusters was high achieving in all of these competencies, therefore making them highly proficient Engineers of 2020. One hundred of 771 mechanical engineers surveyed and 29 of the 234 chemical engineers surveyed fell into this Engineer of 2020 cluster.

Given these previous studies and our new contribution, we see several factors in the classroom that support the creation of design competencies. ME 250, as a hands-on project-oriented design class, supported students in gaining more confidence in their design abilities. They became more confident in each of the design phases we identified. We also took a different view into the specific design competencies associated with human-centered design. The confidence students gained in these skills (for example, *Observing* and *Decision making*) are relevant outside of design. Design courses support students in gaining relevant competencies needed in the real world, inside and outside of the design context.

**References**

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