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Undergraduate Student Learning of Market-Driven Design Topics in a Third-Year Design Course

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Introduction

This short paper summarizes the activities and results of a collaborative Research Initiation in Engineering Formation (RIEF) project studying undergraduate student design conceptions before and after a third-year, project-based engineering design course. Of particular interest is the consideration of topics related to "market-driven design," which integrates consumer, competitor, pricing, and profitability considerations throughout the design process.

Background and motivation

Engineering curricula are typically structured with courses in mathematics, scientific theory, and applied mathematical and physical analysis methods. Despite a decades-long push for design courses and activities, studies show that engineering programs focus too heavily on teaching science and analysis rather than holistic design [1]. This conflicts with the needs of modern society, which requires products that take into consideration factors unrelated to technical skills, such as user needs and sustainability [2]. In other words, technical design does not take place in a vacuum; market and environmental factors play a critical role in design success. In fact, "design in context" that considers consumer needs and market environments is a key success factor for engineered products [3–5]. However, engineering students are graduating without all of the skills that they need to succeed in professional engineering practice [1, 3, 6, 7]. This mismatch between engineering students' educational preparation and the real-world demands of new engineers is referred to by many as a "skills gap" [8–11]. To provide insight into the engineering skills gap, this project explores undergraduate student conceptions of design and how they shift during a project-based design course that introduces "design in context" skills and techniques, including market and financial analysis.

To date, student conceptions of engineering and engineering design have been explored through a variety of methods including surveys, text analysis, and concept mapping [12–15]. The research fields of "decision-based design" and "design for market systems" have been investigating ways to concurrently design for technical performance and market success [16, 17]. However, there is a limited body of literature discussing student conceptions of product design and the design process, and in particular whether and how market considerations are a part of those conceptions, which this project aims to measure and analyze in a quantitative manner.

Research objectives and questions

To bridge the gap between market-driven design and engineering education research, this project explores how students think about and internally organize design concepts before and after exposing them to market-driven design approaches and tools in an engineering design course. The following research questions (RQs) are explored:

- RQ1: To what extent do undergraduate engineering students' initial conceptions of design account for the market context, such as competition and consumer considerations?
- RQ2: In what ways do these design conceptions change after introducing market-driven design techniques and tools in a design course?
- RQ3: What types of student assessment (e.g., surveys, written reflections, project reports) are significant predictors of evolving design conceptions at a topic level? and
- RQ4: Does the introduction and use of a market simulator tool correspond with a change in design conceptions?

By exploring how current students conceptualize design and how that affects their design outcomes, this project supports the design of future education programs that produce engineers with a more balanced perspective on design that accounts for both technical feasibility and market needs.

Research methodology overview

Aligned with the constructivism framework, which asserts that learners construct their understanding of the world through their experiences [18], this project is organized to first understand how students conceive of design, then introduce market-driven design concepts through an interactive course curriculum, and finally observe the ways in which these student conceptions of design evolve or expand. This paper analyzes data collected from 130 undergraduate students enrolled in Engineering Management (EM), Industrial and Systems Engineering (ISE), and Mechanical Engineering (ME) degree programs at Stevens Institute of Technology during a third-year required engineering design course. These students make up the first cohort of a two-year study. The EM and ISE students are taught in a combined section of 23 students (referred to as Section A), where market-driven design is highlighted throughout the curriculum and multiple assignments are collected and analyzed. The ME students are taught in two sections of approximately 54 students each (Sections B and C). In Section A, 43 percent of the students identified as female and 35 percent as non-white, which is typical of national engineering student ethnicity demographics, though more gender-balanced than the national average [19]. In Sections B and C, 19 percent of the students identified as female and 23 percent as non-white, which aligns with national engineering gender demographics but is less ethnically diverse [19]. While the detailed curricula are different between the EM/ISE and the ME courses, both courses are project-based and focused on design of physical consumer products.

Engineering design is a multifaceted topic, and the breadth of relevant subject matter along with differences across engineering disciplines raises challenges in assessing and quantifying student perspectives [20]. One tool proposed to capture such conceptions is concept mapping, due to its versatility and unaided recall nature, for eliciting and visualizing an individual's knowledge surrounding a particular subject [21]. Concept maps are used in this study to capture student knowledge and mental models around the central idea of *product design*, both at the beginning and end of the semester. Every student in the study created pre- and post-course concept maps of their individual understanding of product design. They were first introduced to concept maps along with some examples, and then they were instructed to individually "draw a concept map that embodies the concept of *product design*." From these submissions, the research team was able to assess the frequency of the presence of different concepts and relationships in the maps, allowing analyses of initial conceptions (RQ1) and comparisons between the pre- and post-course contents (RQ2). This provides insights into how different students conceptualize design, what themes are present or absent (such as market-driven design concepts), and whether and how this course changed those conceptions. Term project reports were also collected from all sections to examine the correlations between conceptualizations and implementation and reflection in the context of design projects.

In Sections A and B, an agent-based market simulator [22] was introduced about one-third of the way through the course via a 45-minute workshop. During this time, student teams used this custom software program to evaluate how their early product designs would be expected to perform in a marketplace with consumers and competing products. This required the student teams to conduct background research on competing products as well as consumer preferences, and to make justified assumptions where they were unable to find data. In Section A, two reflection assignments and two surveys—one of each immediately after the simulator exercise and one toward the end of the course—were employed to understand how these students perceived and used the simulator, as well as what they thought they learned from it (RQ3 and RQ4).

To summarize, four data instruments are leveraged to assess these changes in design conceptions:

- Concept maps generated by the students at the beginning and end of the course (Sections A-C),
- Open-ended written reflection assignments about the market simulation experience and learning at two points in the semester (Section A),
- Surveys administered after learning the market simulation tool and at the end of the course (Section A), mainly consisting of Likert-scale questions about perceived learning, and
- Final project reports in which student teams listed their top 3-5 lessons learned in the course (Sections A-C).

Prior to the data collection activities, the participants signed voluntary informed consent forms to permit inclusion in the research. The research plan was approved by the Stevens Institute of Technology Institutional Review Board (IRB) under protocol number 2017-016 (20-R1).

Summary of findings

To address RQ1 and RQ2, the concepts appearing in the concept maps were categorized into themes and subthemes, which emerged through an iterative process as two coders categorized the terms. The themes were *Engineering* (with subthemes *technical skills*, *conceptual development*, *prototyping & testing*, and *manufacturing & production*), *Business* (with subthemes *finance*, *market*, *operations*, and *project management*), *Society* (with subthemes *government & citizens*, *sustainability*, *ethics*, and *standards & codes*), and *General*. Between Sections B and C, there were no statistically significant differences in the pre- or post-course concept map structures or thematic contents. This indicates that the market simulation activity on its own (which took place in Section B but not Section C), without follow-up assignments, had no substantial effect on student conceptualization changes. Therefore, the ME sections were pooled together and treated as a single group for the remaining analyses. When observing the pre-course concept maps alone, there were no significant thematic differences between the EM/ISE and the ME students. Across all students, approximately 40 percent of the pre-course concept map terms were related to *Engineering* and 40 percent to *Business*, with the remaining terms split between *Society* and *General*.

Regarding RQ2, while the EM/ISE students did not show statistically significant changes pre- to post-course at the thematic level, perhaps because of the small sample size (21 students who completed both pre- and post-course maps), the ME sections (84 students) did exhibit changes. In the post-course concept maps, the ME students showed significant increases in *Engineering* and *Society* terms and decreases in *Business* terms. At the subthematic level, the ME students saw significant increases in *technical skills*, *prototyping & testing*, *sustainability*, *society*, and *standards & codes*, and decreases in *finance*, *market*, and *project management*. At the subthematic level there were significant changes for the EM/ISE students as well, with a substantial increase in *market* terms, and decreases in *technical skills* and *society*. Given the emphasis of market-driven design in the EM/ISE course, this change shows that the students are internalizing the material of the course.

To address RQ3, correlations were sought across the various data instruments, looking at specific market-driven design topics. The top-level topics were *Profitability*, *Market research*, and *Modeling & simulation*. *Profitability* includes the subtopics of *costs*, *pricing*, and *sales*; and *Market research* includes the subtopics of *consumers* and *competitors*. Given that prior research shows the ability of concept maps to represent internal constructs and understanding, the change in pre- and post-course concept maps was treated as the response variable, and all other data instruments were used as potential predictors. For each topic and subtopic, regression models were fit using backward elimination. The notable findings show correlations between the earlier reflections and the *consumer* topic, and between the later reflections and the *competitor* topic. The lessons learned from the project reports showed few correlations, and the survey responses were generally not strong predictors. This indicates that (1) reflections are able to indicate meaningful changes in student conceptualizations, and (2) these changes correlate well with the course topic timeline, as the course focused on consumers earlier on and competition later.

To address RQ4, we look specifically at the data collected around the time that the market simulator was introduced (Week 5) and when it was required to be used for reporting results in a team assignment (Week 13). As stated previously, the earlier reflections in Week 5 showed correlations with conceptual change related to *consumer* topics, and the Week 13 reflections showed correlations with changes in the *competitor* topics. This indicates that the simulator, along with the reflection activities and follow-up assignments, may have contributed to design conception changes. However, this attribution is difficult to pinpoint, given that the differences in the pre- and post-course conditions were affected by many things other than the simulator, including the other activities of the course and activities associated with other concurrent courses and extracurricular activities.

Anticipated contributions

This research has theoretical and methodological implications for future engineering design education research and curriculum development. First, it establishes a baseline of student conceptualizations of product design, with thematic and structural data that can be leveraged in future studies. Second, it provides empirical evidence regarding the correlations among different data instruments, quantifying the benefits of reflection assignments over self-assessed learning to represent and evaluate student conceptualizations. Third, it prescribes a methodology that future studies on student conceptualizations can adopt and build on. Fourth, and more specifically to the market simulator, it shows that a 45-minute intervention with an interactive tool does not have a substantial influence on student conceptualization when the activity does not require any follow-up reflections or assignments. Overall, the findings will support future researchers and educators in developing curricula that address "design in context" skills and better meet the needs of the engineering workforce.

The second cohort is taking place during the 2020-21 academic year. The data collection instruments and implementation plan have been revised based on the observations and findings from the first cohort, in order to elevate the rigor of the study and the value of the findings.

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