Understanding student conceptualizations of the market context in engineering design

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Introduction

Studies have shown that engineering students are graduating without all of the skills that they need to succeed in professional engineering practice [1] - [4]. Undergraduate engineering programs tend to over-focus on technical skills and their applications to problem solving and design, leading students to develop internal constructs of design that lack the context in which the design solutions exist. This is reinforced by the available tools for use in engineering education, which are highly focused on ensuring technical feasibility, and a corresponding lack of tools for engineers to explore other design needs. In practice, however, "design in context" that considers consumer needs and market environments is a key success factor for engineered products [2], [5], [6]. 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 [7], [8]. By exploring how current students conceptualize design and how that affects their design outcomes, this study aims to support 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.

To bridge the gap between market-driven design and engineering education research, this study 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 overarching research questions are:

1. To what extent do undergraduate engineering students' initial conceptions of design account for the market context, such as competition and consumer considerations?
2. In what ways do these design conceptions change after introducing market-driven design techniques and tools in a design course?

Guiding Framework

The research activities are guided by the constructivism framework, which posits that learners construct their understanding of the world through their experiences [9]. As a theory of learning, constructivism provides a lens for assessing and explaining how learners learn as they engage with objects in the world around them. Most importantly, this framework offers a rationale for curriculum integration that connects learning with the practice associated with the workplace [10], [11]. Constructivism is often applied when the goal of the study is to describe conceptual structures of the learner, which aligns with the current research goals of investigating the change in students' perceptions of design based on a market-driven approach. Curricular design within a constructivist framework takes into consideration the educational context, pedagogical strategies, and intended student outcomes. These three constructs are represented by the framework through the following principles [11]:

1. Taking advantage of prior knowledge and experience of the learner,
2. Aiming for deep processing of information rather than passive dependence of surface features,
3. Developing metacognitive knowledge that allows students to control their own learning,
4. A focus on emphasizing the key features of the concepts to be learned, and
5. Involving the learner actively in selecting, organizing, and integrating new information.

Methodology

Aligned with these constructivism principles, the research questions are addressed through several exercises that took place with 130 third-year undergraduate engineering students in a course called *Engineering Design VI*, as it is the sixth in an eight-course *Design Spine* sequence. The assessment tools include concept mapping exercises, in-class market simulation workshops, open-ended written reflections, and surveys, as well as the students' term project reports. These tools are summarized with their connections to one another, the research questions, and the constructivism principles in Figure 1.

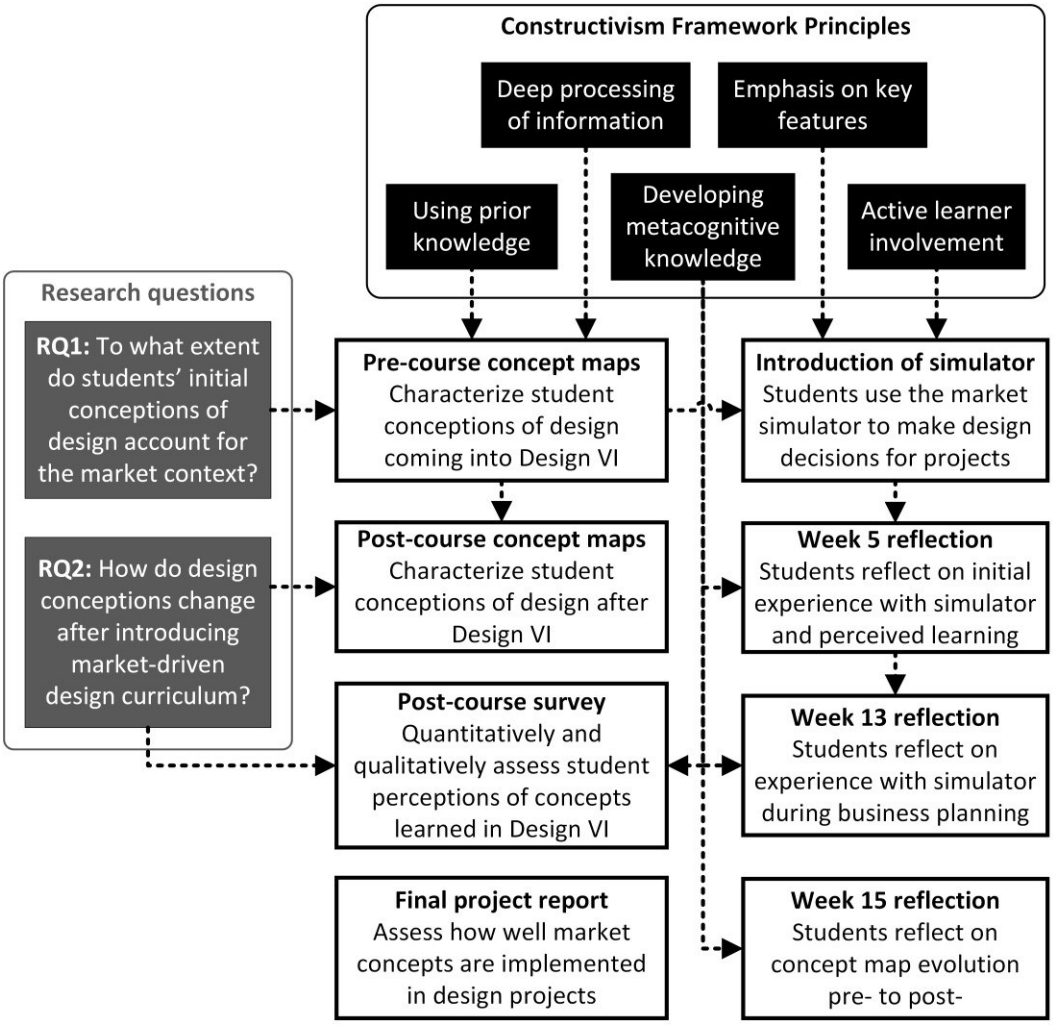

Figure 1: Research activities (white boxes) mapped to the research questions (grey boxes) that they address and the constructivism principles (black boxes) with which they align.

These activities are organized to first understand how students conceive of design, then introduce market-driven design concepts through an interactive curriculum within the project-based *Engineering Design VI* course, and finally observe the ways in which these student conceptions of design evolve or expand.

Current and Future Research Activities

The study is designed around two cohorts of the *Engineering Design VI* course, during the academic years of 2019-20 and 2020-21. In the first cohort, data were collected from 130 undergraduate students in three different programs: Engineering Management (EM), Industrial

and Systems Engineering (ISE), and Mechanical Engineering (ME). The ME students were taught in two different sections, by different instructors but following the same syllabus and course plan. A separate syllabus, course plan, and deliverables were used with the EM and ISE students, who were taught together in one combined section.

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 comparisons across major programs as well as before and after the course. 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 students to examine the correlations between conceptualizations and proper implementation in term projects.

In the EM/ISE section as well as one of the ME sections, an agent-based market simulator was introduced partway through the course via a 45-minute workshop. During this time, student teams used this custom software program to evaluate how their products would be expected to perform in a marketplace with consumers and competing products. This required students to conduct background research on competing products as well as consumer preferences. Including this activity in some sections, but not all of them, enabled a comparison of the post-course concept maps with and without this interactive learning activity. Additionally, in the EM/ISE section, three reflection assignments and a survey were collected to understand how these students perceived and used the simulator, and what they thought they learned from it.

The second cohort will take place during the 2020-21 academic year. The data collection instruments and implementation plan will be 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.

Discussion

This research has implications for both engineering education as well as market-driven design. First, the findings advance our understanding of how engineering students perceive design as a process and how they conceptually balance the technical and non-technical components of design. This provides engineering educators with a stronger foundation for the research and development of effective engineering curricula that build on these student conceptions. Second, the findings help researchers of engineering design to better understand the needs of marketdriven design methods, as they provide a baseline for how engineers are currently approaching design and how receptive they are to the processes and tools from the research community. Overall, the results provide recommendations for how to improve curricula so that engineering students graduate with stronger skills in systems thinking and holistic design.

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