Work in Progress: Design Educators' Conceptions of Prototyping in Engineering Design Courses

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Introduction

This work in progress (WIP) research paper investigates the conceptions of prototyping in engineering design courses from the instructors' perspective. Prototyping is an activity central to engineering design. And the context of prototyping to support engineering education and practice has a range of implementations in an undergraduate engineering curriculum. Understanding faculty conceptions for the reason, purpose, and place of prototyping can help illustrate how teaching and learning of the engineering design process is implemented across a curriculum and how students are prepared for work practice. We seek to understand, and consequently improve, engineering design teaching and learning, through transformations of practice that are based on engineering education research.

Design teaching and learning

Challenges in teaching design exist due to difficulties in framing design problems, recognizing what expertise students possess, and assessing their expertise to help them reach their goals. In project-based learning (PBL), for example, Dym, et al (2005) proposed the questions related to issues of *authenticity* and *assessment*. In one of the questions about "proportions of problems" they shed light on the "problem solving" as one of the key characteristics in design thinking, teaching and learning. According to Jonassen (2000), "Instructional-design research and theory has devoted too little attention to the study of problem-solving processes." In PBL, prototyping activities should help students become more reflective on their design. Lande (2017) suggested that scaffolded activities in prototyping support "self-regulated learning by offloading feedback from the instructor to students' evaluation of their own prototype in the context of iterative feedback from a user." *In this pilot, exploratory study, the research question we try to address is: What are design educators' conceptions of prototyping in design courses?* Understanding these conceptions represents a first step to transform design teaching by employing scaffolded prototyping.

Research method

In this exploratory study, three faculty members who teach engineering design in project-based learning courses in an undergraduate general engineering program were interviewed, listed in Table 1. The instructors were selected both because of their expertise teaching design courses across mechanical, electrical, and robotics engineering concentrations and at one or more level in the curriculum. This enables the capture of these educators' perspective observing the students' progress through the curriculum. This pilot study builds on related work done by the authors that previously investigated undergraduate engineering students' conceptions of prototyping activities and process (REF). With educators participants, an interview protocol (see Table 2) was followed through semi-structured qualitative interviews that carefully aligns with questions also asked to participant engineering students in a related study. Each interview lasted for approximately 30 minutes. Data analysis has been undertaken through an emerging thematic analysis of these interview transcripts. At this exploratory stage, only one researcher conducted

the transcription and data analysis. Inductive coding was used iteratively to arrive at themes. Inductive coding was first applied to one transcript. The same codes were then used to analyze the other two interviews, with emerging codes added to the codebook as necessary. A complete re-coding of the data was then made using the emergent codebook. without imposing previously observed codes on the data.

Table 1. Summary of participants profiles.

Faculty pseudonym	*Area of design teaching experience*
Prof. Anderson	Sophomore *Human-centered* design courses , entrepreneurship courses
Prof. Brown	Sophomore and graduate *Robotics* design courses
Prof. Campbell	Senior Mechanical and Electrical engineering design courses

Table 2. Pilot study semi-structured interview protocol.

- Can you tell me about classes you teach where you ask students to build artifacts?
- What knowledge do you assume students bring to class to build prototypes?
- Do you specify the level of detail you are expecting in prototypes?
- In your classes, what do you consider students build as a prototype or final product?
- Do you give students feedback on prototypes that they make?
- What kind of feedback do you provide?
- Tell me an example of feedback that has changed students' approach to a design challenge?
- How do you give students time to implement the feedback?
- How do students get feedback on prototypes from users, or from instructors?
- How do you introduce prototyping and building artifacts in class?
- Do they start building low-fidelity prototypes or mockups?
- If you had the chance to redo this course again, what would you do differently?
- What do you think the goal of a design course is?

Initial Early findings

Early findings describe (1) *how the design process is related to content knowledge in a design course*, (2) *how design educators provide feedback on students' prototypes*, (3) *students' behavior while working on projects*, and (4) *educators' perspectives on learning objectives*.

Design courses and teaching the design process. Prof. Anderson seems to give lots of focus on teaching the design process to students. She also makes the design process the point of reference when she gives feedback to the students. She seems to be less interested in spending time teaching students how to use the equipment in labs, as she assumes that the come to her sophomore class with the knowledge of how to use the equipment. Similarly, Prof. Campbell who teaches the senior design course does not teach the design process, and states that, "the assumption is that they would come and have some, having understood the design process." Prof. Brown teaches a robotics class that takes a systems approach to design in order to integrate mechanical and electrical concepts. He observes that, due to the nature of his graduate-level course, challenges exist because "it's a big umbrella, for disciplines and subdisciplines." He layouts his expectation as, "I don't expect they actually have much. I expect that they are comfortable in learning quickly."

The variation in expectations regarding the understanding level of the design process points to an important issue regarding the lack of standard to the learning objectives in design and what constitutes design knowing. In the design literature, the lack of orderly delineation of what constitutes design content knowledge (Andrews & Goodson, 1980) and design pedagogical content knowledge (Shulman, 1986) is present. Consequently, compared to other courses in the engineering curriculum, students conducting design activities go through different experiences in design courses that lack a coherent structure or framework.

Prototypes and educators' feedback. Prof. Anderson reports that students in her class don't have time to do multiple iterations on their projects, although all students benefit from the feedback she provides. She observes that students tend to give good feedback to each other, sometimes better than the instructor. In her feedback, Prof. Anderson tends to ask students why they made certain decisions and why they went in a certain direction; with students not always having answers to these questions. Prof. Campbell says that no feedback is expected at the senior level, "We provided no guidance overall." In contrast, Prof. Brown effectively uses iterations on prototypes by meeting individually with teams to discuss progress:

> "*I really try to encourage them to see that the process is iterative and that if they don't change their model, their kinematics, their mechanism design to real-world measurements, that somehow improve their design in the next scope, then they are not achieving the projects goals set as I outlined it.*"

The variety of level of depth of feedback provided points to critical issues regarding the actual learning that takes place in design courses. Moreover, these design educators have indicated the time-consuming process that feedback in design classes requires. These early observations point to a lack of standard regarding the sequencing of design knowledge. The need to provide templates for design curricula and assessments (Duncan, & Hmelo-Silver, 2009) as well as selecting appropriate design pedagogies to assess learning progressions (Songer, Kelcey, & Gotwals, 2009) is certainly needed.

Students' behavior while working on projects. Prof. Anderson says that students are all about the construction of the project; they tend to think less about why they do what they do. She also says that when they build low-fidelity prototypes, they do it because they are asked to do it, not because they see the value of it. In the design literature, the characterization of "premature commitment" to ideas by novice designers has been provided as an illustration of lack of comprehensive understanding of the solution possibilities (Cross, Engineering design methods: Strategies for product design, 2000). Prof. Brown mentions that there were no teams that he supervised that actually used prototyping to understand the design problem:

> "*I don't recall any teams that I was aware of that prototyped or did rough prototyping in order to get shape and form and stuff like that.*"

Prof. Campbell pointed to his emphasis on using the prototype in one iteration to get insight and inform the second iteration:

> "*I am pretty clear that I don't care if your robot doesn't navigate in the world. I care if your robot knows if it is hopping better or worse compared to the last robot. So I put an emphasis on sensing, theoretical sensing on board of the current robot design, and use that for the sensing you need in previous analysis.*"

The comparison between the responses indicates differences of focus among design educators to the centrality of prototyping in the design process, which consequently affects students' understanding of prototyping in design. There is a need to allow students to frame the problem correctly (Cross, 2011), structure the problem (Goel & Pirolli, 1992) and follow a scaffolded process for designing and prototyping (Lande, 2017).

Perspectives on the learning objectives in a design course. In this theme, educators reveal what they value in design courses. Prof. Anderson had opinions on what should be the objectives in teaching a design course as ones that focus on entrepreneurship. She says that there are challenges in coordinating within a group of instructors when everyone comes with their own perspective. The lack of standards in design education has been discussed in the design literature (Dym, et. al. (2005). In addition, the link between design courses and industry was highlighted in the educators' responses. Prof. Anderson says that she saw less value in teaching the students how to 3D print or use other tools to prototype because students will probably not use this on a professional job. Prof. Campbell observes the importance of collaborating with industry partners as they tend to provide the most realistic feedback and more effectively. In addition, students seem to get more insight by interacting with actual stakeholder. As for the level of difficulty teaching design courses, Prof. Campbell suggests that it's easier to teach design in the upper level classes compared to the beginning students:

> "*I think it's easier. I think it's easier, because they're more experts. They've had four years instead of two years. And so most likely they have had engineering as undergrads, and so that has prepared them very well in making something.*"

In mapping this learning trajectory of learners, Duncan & Hmelo-Silver (2009) suggested providing a lower anchor for the expected background of the learner, and a higher anchor for the expected achievement at the end of the learning experience. Overall, design courses, being taught by different educators from different backgrounds and perspectives, seem to point to lack of coherence in the students' experience in learning design.

Future work

Understanding faculty conceptions of prototyping can shed light on the efficacy of using prototyping as an authentic experience in design teaching and learning. In project-based learning courses, particular issues of *authenticity* and *assessment* are under consideration, especially across the curriculum. In this pilot, exploratory study, we were able to identify variations in perspective, expectations and approaches to teaching prototyping in design courses. We intend to expand the design educators participants in a future study, comparing educators from both a traditional curriculum and a design spine curriculum. In addition, we intend to compare conceptions between educators and students. Ultimately, we aim to improve understanding of prototyping in design education and learning. Scaffolded activities in prototyping can support self-regulated learning by students.

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