

Learning Trajectories Through Learning Making and Engineering, and Implications

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This NSF EEC EAGER research project investigates how undergraduate STEM and engineering students' learning trajectories evolve over time, from 1st year to senior year, along a novice to expert spectrum. We borrow the idea of "learning trajectories" from mathematics education that can paint the evolution of students' knowledge and skills over time over a set of learning experiences (Clements & Sarama, 2004; Simon, 1995; Sztajn et. al., 2012; Corcoran, Mosher & Rogat, 2009; Maloney and Confrey, 2010). We use a theoretical framework based on adaptive expertise and design thinking adaptive expertise to further advance a design learning continuum (Hatano and Inagaki, 1986; Schwartz, Bransford & Sears, 2005; McKenna, 2007; Neeley, 2007).

Project Overview

This research project has been to explore and understand how open-ended, hands-on making work and activities are reflected in the learning trajectories of students and their learning gains in the product-based learning, undergraduate engineering classroom. The aim is to expand understanding of making learning in the context of engineering design education and to illustrate educational pathways within the engineering education curriculum.

The main research questions of this project are:

- 1) How do engineering students learn and apply making?
- 2) What are the attributes of making in the engineering classroom?

We have been focused on how students conceptualize making through their experiences in a product-based learning course engineering design course. We have explored a broad set of different contexts for learning and how to apply these frameworks including making activities and the undergraduate engineering classroom. Below are summaries of individual research efforts that make up this larger research project.

Making-Based Pedagogy

- "We are interested in using our ongoing work to address 'how the attributes of Making might translate to an engineering classroom context?'" (Lande, Jordan, & Weiner, 2017).
- "The basis for proposing such guidelines for Making-Based Learning is in the synthesis of our findings from a broader, ongoing multi-year set of qualitative research studies exploring Making, pathways of Making, and Making within engineering education (Jordan & Lande, 2016; Lande & Jordan, 2014; Lande & Jordan, 2016; McKenna, Kellam, Lande, Brunhaver, Jordan, Bekki, Carberry, & London, 2016). We summarize emergent themes from our ongoing work alongside examples collected from Makers, with examples from our respective experiences teaching engineering" (Lande, Jordan, & Weiner, 2017).

- “Makers are a growing community of STEM-minded people who bridge technical and non-technical backgrounds to imagine, build and fabricate engineering systems. Some have engineering training, some do not. We explored the educational pathways of adult Makers and how they intersect with engineering” (Foster, Jordan, & Lande, 2017).
- “This research is guided by the following research questions: (1) What can we learn about the educational pathways of adult Makers through the lens of constructivist grounded theory? and (2) How do the educational pathways of Makers intersect with engineering? This study relied on qualitative interviews, using artifact elicitation interviews and constructivist critical incident technique interviews, of adult Makers. Through inductive analysis of a collection of interviews with Makers, a theme emerged where Makers from different educational backgrounds and with different careers (e.g., art, STEM, business) were making artifacts that had similar purposes. We present two cases of parallel pathways, (1) musical artifacts and (2) large-scale interactive artifacts, to demonstrate the multiple, parallel life pathways that Makers take to making their artifacts and the contextual events and activities that are critical to the direction of these pathways. The stories and life pathways of adult learners engaged in Making can offer valuable insight into how we might identify practices that promote the access and success of a larger and more diverse population of students in engineering. Makers are engaged in activities that embody the Engineer of 2020 (e.g., lifelong learning, creativity, and practical ingenuity). By studying Makers, we can consider the multiplicity of pathways into engineering majors and careers” (Foster, Wigner, Lande, & Jordan, 2018).
- “Making incorporates many of the key personal attributes of the Engineer of 2020. Although educators have started to institutionalize this connection through the establishment of makerspaces and Maker-based curriculum, less effort has been made to understand how the current population of “grassroots” Makers have come to identify with this movement.” (Weiner, Lande & Jordan, 2017).
- “We [have] analyze[d] critical incident interviews of young adults who frequent shared-use community workshops, or makerspaces. Employing a theory-driven thematic analysis, we developed an initial process framework for Maker identity formation that could provide educators with a useful perspective when implementing Maker-based programs in their institutions” (Weiner, Lande & Jordan, 2017).

Prototyping as a Learning Tool/Experience

- Prototyping in design provides ways to navigate ambiguity in the design problem, gain insight through the refinement of ideas, and aid in communication between team members. However, while designing, students often underutilize prototyping and do not consider it as an integral part of the design process. To facilitate the scaffolding of design activities, it is necessary first to understand students’ conceptions of prototyping. ...[W]e use artifact elicitation interviews as a method to elicit students’ conceptions by moving from the specifics of the artifacts they brought with them to the interview, to their general understanding of prototyping. Participants in the study are students in an undergraduate sophomore design- oriented, project-based learning course in a large southwestern university. The findings of the study describe students’ conceptions of “what counts” as a

prototype; what is valued in a prototype; the benefits of, and challenges associated with prototyping; and differences between in-class and out-of-class prototyping activities. The findings of this study improve our understanding to effectively scaffold prototyping activities in design and experiential learning” (Ali & Lande, 2018).

- “Practical ingenuity is demonstrated in engineering design through many ways. Students and practitioners alike create many iterations of prototypes in solving problems and design challenges. While focus is on the end product and/or the process employed along the way, this design methodology study combines these interests to better understand the product and process through the roles of initial prototyping through the creation of such things as alpha prototypes, conceptual mock-ups, and other rapid prototypes. We explore the philosophy behind the purposes and affordances of these low-fidelity prototypes in engineering design activity. Two research efforts are described that explore the roles of low-fidelity prototyping in engineering design activity. A study using student prototyping examples is shared to connect the research to practice. Then, an analysis of textbook presentations of prototyping is also shared to both provide a possible basis for this gap and an opportunity to bridge this gap. By better understanding the literature basis for low-fidelity prototyping, how it is practiced by students in a course, and how textbooks present prototyping as a concept, this paper can help identify areas to improve teaching of this core engineering design topic and support the development of student engineers practicing practical ingenuity” (Ali & Lande, 2019a).
- “Another research thread 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” (Ali & Lande, 2019b).
- “The practice of prototyping is challenging to novice designers as they underutilize insights that prototyping offers to solving design problems. Central to this challenge is the abstract nature of design concepts like idea representation, iteration, and problem solution-space exploration. A unique opportunity from mathematics education presents itself for design educators and facilitators; that is, teaching with manipulatives. We seek to transfer such practices in mathematics education to design education and practice. Challenges exist for design researchers to carefully craft activities in design education mainly because of the open-endedness of problems, decision-making that takes place while designing, and the inherent uncertainties in the design problems. Ultimately, the goal is to develop students’ ability to flexibly transfer expertise to other contexts and new design challenges” (Ali, Kinach, & Lande, 2019).

Impacts

By sharing learning trajectories across multiple communities, we seek to change the conversation by illuminating pathways for a wider array of student makers to become the makers and engineers of the future. The results of this study generated during this study will describe the learning trajectories of engineers learning making. By examining the engineering student making learning experience this work can impact the quality of engineering design teaching. This study will highlight routes to making learning that can illustrate pathways to engineering and a means to adopt a making mindset approach that is more inclusive.

Students learn and re-learn design thinking and the design process by doing authentic activities in project-based learning. Students learn and re-learn design thinking through the act of repeatedly experiencing a design process coached by instructors, with each iteration improving on their procedural skills and synthetic knowledge to create anew. The design process serves as a cognitive apprenticeship; each constructive design activity and design experience, through interaction with teammates or coaches, gives students opportunities to refine their model of design and design practice. Each interaction taken under the guise of a step in the design process helps the learner compare and contrast to their own mental model and forces the learner to clarify and rectify their model with their experience. Repeated design experiences serve to advance the student's model of design thinking and the design process to become better designers, engineers, and makers.

The concept of learning trajectories can be generalized across the fields of engineering and other STEM disciplines and beyond. There is some overlap already with the concept of learning trajectories shared from mathematics education. It is hoped that the concept of learning over time can be conceptualized, mapped, visualized and shared. The specifics for an engineering design process may be differentiated across disciplines but it can be applied nonetheless. We hope to be able to use design and making as a means to make such connections.

By examining the engineering students' learning experience through the lens of cognitive science and establishing a framework for assessing the Design Thinking Learning Trajectory, this work can impact the quality of design teaching and inspire industry to offer methodologies to mediate multi-disciplinary collaborations. Coming to understand (scholarship of merit) (Lande, Adams, Chen, Currano & Leifer, 2007) and promoting the efficacy of project-based learning and design thinking (scholarship of impact) are the expected results of this project.

This project provided opportunities for research, teaching and mentoring in science and engineering areas. In supporting the learning of students, it can be a means to figure out a means to support learning in the ambiguity of design and making contexts.

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