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Student Learning Trajectories from Making and Engineering Activities

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Introduction

The research objective of this NSF-funded *EAGER: MAKER: Student Learning Trajectories from Making Activities Learning Trajectories* project is to explore and understand how open-ended, hands-on Making work and activities can reflect student learning trajectories and learning gains in the product-based learning, undergraduate engineering classroom. The aim is to expand understanding of what Making learning in the context of engineering design education might be and to illustrate educational pathways within the engineering education curriculum.

The main research questions are (1) How do engineering students learn and apply Making? and (2) What are the attributes of Making in the engineering classroom? Traditionally, engineering design is taught as a means for students to synthesize their engineering content knowledge in capstone courses. These design courses are usually successful, in that the students do well, they come up with innovative solutions, and they are satisfied with their school experience and feel ready for the real-world. But, what have they actually learned about solving ambiguous problems and integrating Making into their design thinking, engineering doing, and the design process? The American Society for Engineering Education has generated reports [1], [2] on the role of Making within an engineering context.

What does it mean to learn Making? Does the student's own understanding of the engineering design process change as a result of such experiences, and how? Many engineering faculty report on "cool stuff" they do in class in support of learning but few bolster their reports with evaluations of the student learning or ground them in prevailing cognitive science or educational psychology [3]. This study aims to work towards understanding the cognitive process in Making, design and engineering learning, and propose a framework of and assessment for learning. The aim is more effective teaching. It can also add another facet of diversity when constructing student and industry teams and suggest a shared approach to multi-disciplinary collaborations.

Making and Engineering

Engineers participate in the Maker movement. Some Makers do not pursue formal engineering education but both the engineering field and their own vocational advancement could readily benefit. We seek to understand Making and how Making activities and work are inclusive or exclusive of what we expect from engineers and engineering students. From the *Engineer of 2020* [4], we highlight *practical ingenuity*, *creativity* and *lifelong learning* for likely opportunities to leverage the Maker experience in the engineering classroom experience. With an ultimate goal of facilitating more effective teaching and learning of Making through the experience of learning engineering and design in the undergraduate engineering classroom, this research aims to develop a mapping or trajectories of learning, and a framework for assessing it. A maker is a modern-day tinkerer, hands-on doer and fashioner of stuff who creates technical artifacts often without prior expertise [5]. The range of Makers' expertise could be large, but novices and experts alike share an enthusiasm and appreciation for building, creation, and work under the additive innovation philosophy.

Methods

Empirical evidence of what Making in the engineering classroom looks like, and how it changes over time, and how students conceptualize Making through Making, designerly, and engineering ways of knowing-doing-acting comes from collection and qualitative analysis of student project data collected during a product-based learning course engineering design course. We aim to triangulate what students think they are learning, what they are being taught, and what students are demonstrating. Students are recruited from the range of courses in our academic unit's project-based design spine from freshmen to senior years, supplemented by additional courses across our university. For this instance of reporting on this research project, we focus on two methods used thus far:

Content Analysis: Student Concept Maps of the Making Design Process
Students in selected courses are asked to complete a short questionnaire asking them to "Draw your Making process." Maps are classified along the spectrum and developmental range of the student design learning continuum (Figure 1, next page). A subset of students are selected to review their maps and perform talk alouds to elucidate further descriptions and reasoning within their process.

Semi-Structured Interviews: Teaching Team and Students
To get at the pedagogical and philosophical approach of teaching Making thinking, semi-structured interviews are done quarterly with professors, teaching assistants, coaches and select students. What students do and what students are perceived to have learned as well as conceptual blocks to learning will be captured, and an emerging thematic analysis will inform other prongs of the research.

Categorizing Learning Trajectories

Individual engineering design process (as recorded over time) can be used as a summative and formative assessment tool to gauge the student's learning in design and engineering courses. Based on empirical work and learning theory we propose a spectrum of cognitive mental models or possible representations of the design process inclusive of design thinking and engineering doing that advances from novice to intermediate to expert. The novice-to-expert transition of design expertise or continuum of design expertise is still undefined. Atman et. al. [6] have characterized the relative design processes of college freshman and seniors, design educators and practicing designers. Based on individuals constrained (both by time and scope of problem) in a lab setting, Atman et al. were able to identify and describe differences in design process practice, namely, time on problem definition, chronology of process, and iterative steps. Limited to observation in lab and not in situ they followed up with a generative question of their own of how a student's design learning continuum could look like visually. Building on previous work [7], [8], including design process maps collected thus far we present a spectrum and developmental range of a student's design learning continuum, see Figure 1.

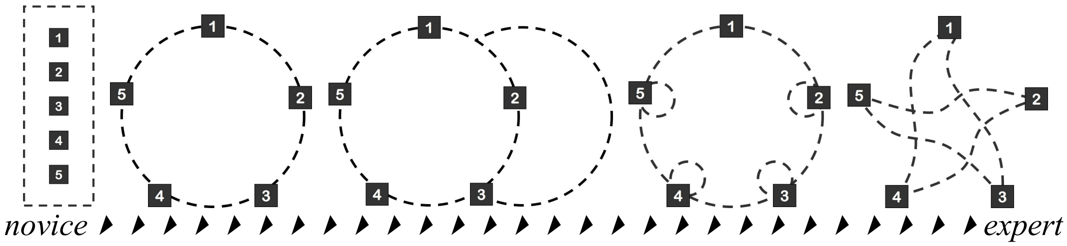

Figure 1: Spectrum and Developmental Range of a student's design learning continuum [9]; ideal design process models from novice to expert, (l-r): linear, circular, successive, iterative, interwoven.

Novice designers first report concept maps of the design process in Linear (horizontal or vertical) fashion. Connections made to the Circular nature or Successive nature of the design process create maturing models. An advancement to the appreciation of the Iterative nature of the design process is where most student designers get to during their education. Neeley [10] developed a framework for adaptive expertise that models the way that the industry expert designers behave where the design process evaporates and the expert uses the normative design steps as an Interwoven number of possible tools to apply strategically. Below, in Figure 2, sample design process concept maps are shown.

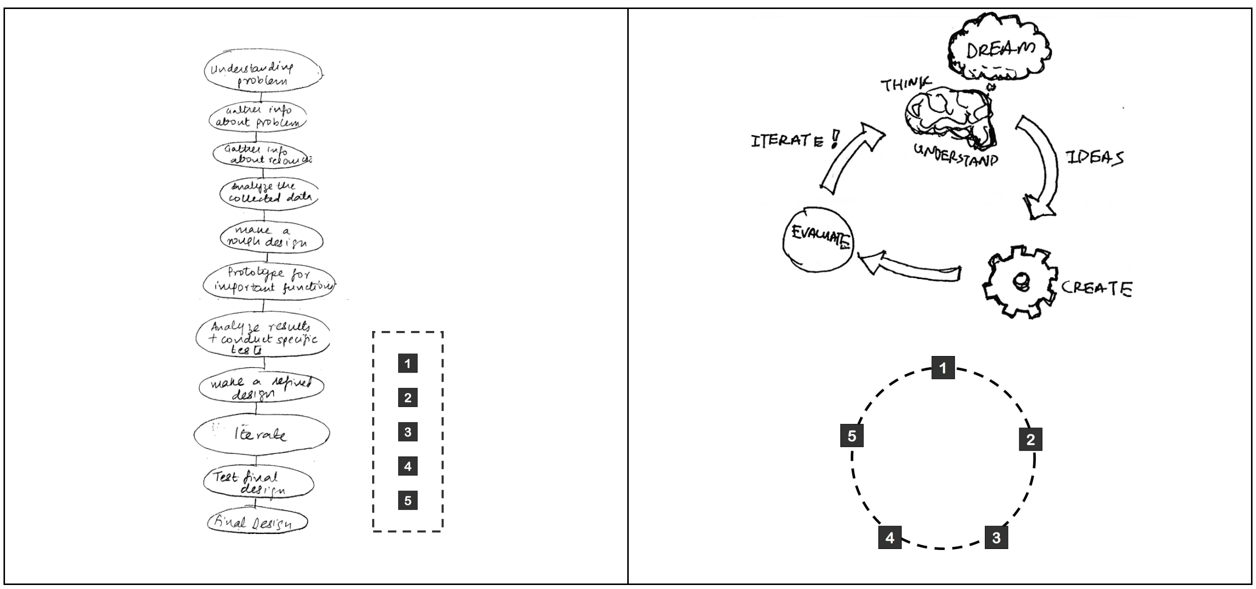

Figure 2: Sample student concept maps: (L) linear, (R) circular [8]

Generative List of Learning Attributes of Making

Making is rooted in constructionism – learning by doing and constructing knowledge through that doing. Aspects of Making work and activities that are unique to Making that could appear in the engineering classroom or curriculum include [11]:

1. Sharing: Sharing both recipes and artifacts (one-to-many) with both others and interested spectators. They celebrate and learn from others' accomplishments, and openly accept criticism to improve their designs (many-to-one).
2. Practical Ingenuity: Building & prototyping using available materials, tinkering via iterations.
3. Personal Investment: Being strongly invested and motivated to work on projects. Caring because they are personally interested in their projects, and take ownership over the solutions they take.
4. Playful invention: Exhibiting creativity, novelty, and play in their creations. Inventing a future.
5. Risk Taking: Treating failure as a badge of honor and admission into their community. Having the confidence to try creative solutions and learn by doing, failing, and doing again.
6. Community Building: Seeking connection with others and operate in shared social communities. Rather than do-it-yourself, it's do-it-together. Participation is the (non-exclusive) means for membership. Collaborate without competition, community retains knowledge.
7. Self-Directed Learning: displaying aspects of lifelong learning and self-direction.

Additional, specific skills related to Making in the context of engineering courses may also include multiple representations, visual thinking, a connection to real world, levels of abstraction, creativity, and application to engineering content.

Conclusions

There is a presumption that Making is relevant for the engineering education enterprise. It may also diversify the students brought to STEM pathways. Making may allow for real world practice and highlight a means to bring more real world problems that people care about forward. If this is all correct, it could have a grand impact on how we may teach engineering via Making.

This work is exploratory in nature. In my approach to understanding Making outside of formal engineering education, at events like Maker Faires in the Maker Community, it does seem evident that there is a lot of overlap between a Making mindset and a designerly way of knowing or engineering way of knowing. In the sphere of formal engineering education however, Making is regularly viewed as lesser than engineering, perhaps engineering design without the engineering science or analysis. Making is not yet valued as part of formal engineering education efforts. It will be interesting to find evidence of student learning through Making in the engineering classroom. It could have large impact to appreciate the role of design thinking, innovation, prototyping, etc. for the engineering classroom.

If Making is something that can be connected to beneficial student learning and is additive to the required technical content *and* provides a means for students to figure out what area of problems they want to tackle in the studies and beyond, it would make for a student-centered Making revolution.

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References

1. American Society for Engineering Education, "Envisioning the future of the Maker Movement: Summit report," American Society for Engineering Education, Washington, DC, 2016.

2. American Society for Engineering Education, "Advancing the Maker Movement: Making and makerspaces at engineering and engineering technology schools and departments and the non-engineering academic maker community, American Society for Engineering Education, Washington, DC, 2017.

3. W. Newstetter and W. McCracken, "Novice conceptions of design: Implications for the design of learning environments," in *Design Knowing and Learning: Cognition in Design Education*, C. Eastman, W. C. Newstetter and M. McCracken, Eds. Oxford, United Kingdom: Elsevier, 2001, pp. 63-77.

4. National Academy of Engineering, *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, DC: The National Academies Press, 2004.

5. S. Jordan and M. Lande, "Might young makers be engineers of the future?" in *Proceedings of the Frontiers in Education conference, Madrid, Spain, 2014.*

6. C. J. Atman, M. E. Cardella, J. Turns and R. Adams, "Comparing freshman and senior engineering design processes: an in-depth follow-up study" in *Design studies*, vol. 26, number 4, pp. 325-357, 2005.

7. R. S. Adams, J. Turns and C. J. Atman, "What could design learning look like?" in *Proceedings of the Design Thinking Research Symposium VI. Sydney, Australia, November 2003.*

8. M. Lande and L. Leifer L, "Student representations and conceptions of design and engineering," in *Proceedings of the Frontiers in Education conference, San Antonio, TX 2009.*

9. M. Lande, “Ambidextrous mindsets for innovation: Designing and engineering,” Ph.D. dissertation, Mechanical Engineering Design Group, Stanford University, Stanford, CA, 2012.

10. W. L. Neeley, “Adaptive design expertise: A theory of design thinking and innovation,” Ph.D. dissertation, Mechanical Engineering Design Group, Stanford University, Stanford, CA, 2007.

11. M. Lande, S. Jordan and S. Weiner, “Making people and projects: Implications for making-based learning,” in *Proceedings of the American Society for Engineering Education Pacific Southwest Regional conference, Tempe, AZ, 2017.*