Exploring Making-based Pedagogy in Undergraduate Mezzanine-level Engineering Courses

Mr. Michael Scott Sheppard Jr., Arizona State University

Michael Scott Sheppard Jr. is a graduate research associate pursuing a Master of Science degree in Engineering and a Ph.D. in Engineering Education Systems and Design at Arizona State University. He received a B.S. degree in Biomedical Science from Lynchburg College in 2002, after which he served in the military for 6 years as a Special Amphibious Reconnaissance Corpsman. Following military service, Michael obtained a B.S. degree in Engineering from Arizona State University, graduating in 2013. His research interests include veterans in engineering, veterans with service-connected disability, post-traumatic stress disorder (PTSD), and human sex trafficking.

Dr. Shawn S. Jordan, Arizona State University, Polytechnic campus

SHAWN JORDAN, Ph.D. is an Associate Professor of engineering in the Ira A. Fulton Schools of Engineering at Arizona State University. He teaches context-centered electrical engineering and embedded systems design courses, and studies the use of context in both K-12 and undergraduate engineering design education. He received his Ph.D. in Engineering Education (2010) and M.S./B.S. in Electrical and Computer Engineering from Purdue University. Dr. Jordan is PI on several NSF-funded projects related to design, including an NSF Early CAREER Award entitled "CAREER: Engineering Design Across Navajo Culture, Community, and Society" and "Might Young Makers be the Engineers of the Future?," and is a Co-PI on the NSF Revolutionizing Engineering Departments grant "Additive Innovation: An Educational Ecosystem of Making and Risk Taking." He was named one of ASEE PRISM's "20 Faculty Under 40" in 2014, and received a Presidential Early Career Award for Scientists and Engineers from President Obama in 2017.

Dr. Micah Lande, Arizona State University

Micah Lande, Ph.D. is an Assistant Professor in the Engineering and Manufacturing Engineering programs and Tooker Professor at the Polytechnic School in the Ira A. Fulton Schools of Engineering at Arizona State University. He teaches human-centered engineering design, design thinking, and design innovation project courses. Dr. Lande researches how technical and non-technical people learn and apply design thinking and making processes to their work. He is interested in the intersection of designerly epistemic identities and vocational pathways. Dr. Lande received his B.S in Engineering (Product Design), M.A. in Education (Learning, Design and Technology) and Ph.D. in Mechanical Engineering (Design Education) from Stanford University.

Dr. Ann F. McKenna, Arizona State University, Polytechnic campus

Ann F. McKenna is a Professor in the Ira A. Fulton Schools of Engineering and Director of The Polytechnic School at Arizona State University. Prior to joining ASU she served as a program director at the National Science Foundation in the Division of Undergraduate Education, and was on the faculty in the Department of Mechanical Engineering and Segal Design Institute at Northwestern University. Dr. McKenna received her B.S. and M.S. degrees in Mechanical Engineering from Drexel University and Ph.D. from the University of California at Berkeley.

Exploring Making-based pedagogy in undergraduate engineering courses

Abstract

The purpose of this study is to better understand how utilizing Making as a pedagogical approach can increase student engagement and transfer of knowledge in engineering courses. Techniques of engagement and knowledge transfer in engineering education are continuously evolving to meet the growing expectations for developing students' skill sets, mindsets, and technical competency necessary to solve increasingly complex engineering problems. One such technique is the growing influence of the Maker movement into engineering curricula. Makers represent a culture encompassing, but not limited to, students and entrepreneurs that are technology-driven toward the creation of physical objects or software to gain a better understanding of engineering properties, concepts, and practical problem-solving skills. This work in progress (WIP) paper provides an overview of our study that explores how elements of Making have been integrated into specific engineering courses to emphasize real-world context, and increase student engagement.

We utilized a case study approach of three engineering courses at Arizona State University. These courses were selected to reflect three distinct required subject areas that fall within the mezzanine, which designates the middle sophomore and junior years. Our case study approach includes data collection through faculty interviews, observations, and course related documents. Preliminary analysis of the interview data reveals that faculty members utilize Making approaches in a variety of ways. Evidence of Making in the engineering curricula includes aspects of active learning, "building" something to represent concepts, as well as having students connect concepts and ideas to real world contexts. This work in progress presents a brief review of the literature that guides this work, an overview of the study, insights from the preliminary data analysis, and a discussion of future work.

Literature Review

In a status report for the National Research Council's Board on Science Education, Fairweather[1] argues that we currently have ample evidence that demonstrates the effectiveness of student-centered teaching, and that we should redirect our efforts from producing more evidence to getting more STEM faculty to engage in student-centered teaching practices. One way to integrate student-centered learning into the classroom is to introduce Making into the curriculum. A "Maker" is a modern-day tinkerer, hands-on doer and fashioner of stuff who creates technical artifacts often without prior expertise[2-7]. The range of a Maker's expertise could be large, but novices and experts alike share an enthusiasm and appreciation for building, creation, and an approach to work that aligns with an "additive innovation" philosophy. Additive innovation is a term that is intended to embed the idea that innovation is inspired through sharing, resulting in adding to the innovation process[8]. Individuals and groups embark on projects of all sorts, based on their interests and curiosities, and informed by their skills or the skills they want to learn.

The *Engineer of 2020* report includes elements that align with Making such as practical ingenuity, creativity, and lifelong learning[9]. Makers embody the twenty-first century skills of creativity and innovation, critical thinking and problem-solving, and communication and collaboration[10]. Research has shown that Making in education has positive impacts on students' adaptive expertise and creativity[11].

Conceptual framework for case study analysis

Given that the focus of our case studies was on faculty approaches to teaching within the mezzanine courses in an engineering program, we needed a framework that enabled documenting the different facets of what the case might entail. We adapted the conceptual framework of *The College Experience*[12] combined with the Quality Matters rubric[13] for instructional design as a way to describe the details of the case. The College Experience Framework captures influences and outcomes associated with the "system" and context surrounding the design and implementation of course innovations, and the culture, attitudes, and beliefs of the faculty member, see Figure 1.

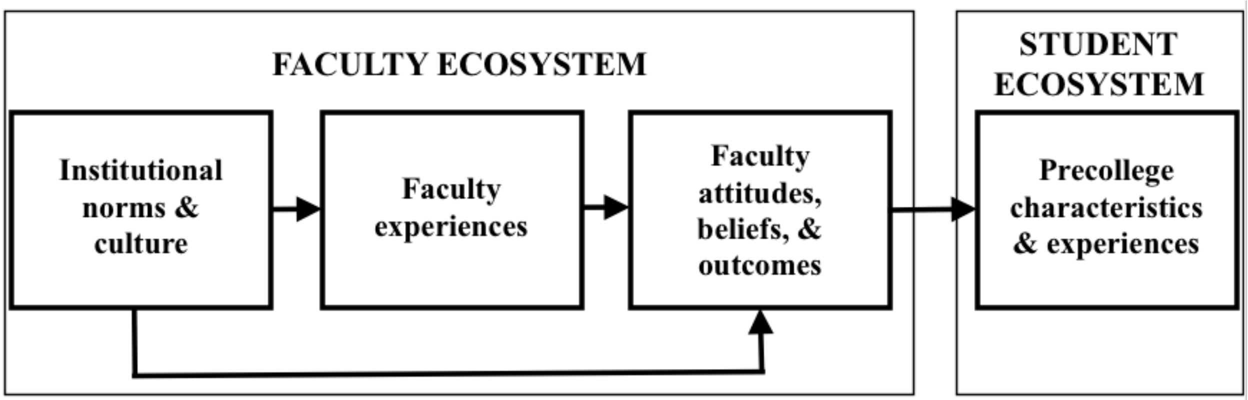

Figure 1. Systems framework of influences on faculty and student beliefs and outcomes[12,14]

The Quality Matters program focuses on designing a process for course quality assurance. This scalable process is presented in a rubric, which offers course design standards and a replicable process for peer review[13]. Below are three of the main Quality Matters foci:

- Train and empower faculty to evaluate courses against these standards
- Provide guidance for improving the quality of courses
- Certify the quality of online and blended college courses across institutions

Methods

We utilized a case study approach[15] of three mezzanine engineering courses at Arizona State University. These courses were selected to reflect three distinct required subject areas that fall within the mezzanine: statistics, robotics, and statics and dynamics. This institution uses a project spine curricular approach, meaning that students are required to complete a project-based class in every semester of the program. Mezzanine courses can be described as courses that align with and intellectually support the students' current and future project courses. Our interview protocol included prompts to explore institutional/cultural aspects of the program, how faculty members define what Making means to them, and how Making-based techniques were implemented in their classroom. A multiple (three) case study analysis was conducted, with the unit of analysis being a single course. Below are examples of a few interview questions:

- Tell me about some aspect that you think is unique about the engineering program?
- What do you do in any of your classes that exhibit this uniqueness?
- Can you tell me about an assignment where students create something physical?
- How do you describe “Making” and how you see students "Making" in your class?

The interviews were transcribed verbatim and were analyzed to isolate, compare, and contrast emergent themes using the frameworks of the College Experience and Quality Matters. Along with interview transcripts, we examined course syllabi, and supporting materials for the Making assignments.

We approached this case study through iterations of coding. First cycle coding utilized both descriptive coding and in vivo coding techniques. Using these two coding techniques we summarized the passages with descriptive verbalization and the selection of powerful participant quotes. Following the initial coding of the transcripts, code mapping was used to lump very specific codes into categories that were broader and more encompassing. Second cycle coding was then employed through a combination of pattern coding and the implementation of an appropriate theoretical framework.

An adaptation of *The College Experience* and *Quality Matters* was applied during this second cycle, which allowed for the lumping of all broad codes into four dominant categories associated with engineering instruction: (1) external environment of institution norms and culture, (2) faculty members’ prior learning experiences, (3) the faculty members’ internal attitudes, beliefs, and expected outcomes, and (4) the curriculum design of their mezzanine course. Throughout the iterative coding process, we frequently met to discuss findings.

Background of the engineering program

This degree program for this study is ABET accredited under the general engineering criteria. The program describes its focus as interdisciplinary, with students sharing a common first two years then choosing one of four concentrations areas at the start of their junior year; Automotive Systems, Electrical Systems, Mechanical Engineering Systems, or Robotics.

Preliminary findings

Analysis of the interviews suggest that each faculty had unique viewpoints on Making and applied different approaches to Making-based implementation in the classroom. One commonality across all three interviews was the description of the uniqueness of the engineering program and its focus on project-based learning. All participants mentioned that having project courses each semester enables students to reinforce engineering knowledge and skills learned and taught in the supporting mezzanine courses.

Case details

Case A focuses on a junior level robotics course that mentioned explicit aspects of Making and the educational benefits. This course is very hands-on, but in a sequenced, intentionally scaffolded manner. The primary objective of this course is for students to gain proficiency in the basics of robotic design and analysis, focusing on kinematics of linkages, actuation and feedback motion control, and sensors and machine vision. Specifically, the course objectives outlined in the syllabus are as follows:

1. Students can analyze robotic systems commonly found in industry, including manipulator components and types, forward and inverse kinematics, and coordinate transformation.
2. Students are familiar with the terminology and basic concepts fundamental to robotics design, can design appropriate simple robotic systems to accomplish a task in a manner that is effective and safe.
3. Students can distinguish between open-loop and feedback control for velocity and position of a single joint and can implement feedback for single-joint position control.
4. Students are able to select appropriate sensors, and make use of digital and analog sensors (including visible-light cameras) to obtain and utilize information in a robotic system.

The course is structured in a way that a seemingly impossible final deliverable, a functioning robot, is broken down into a planned and sequenced set of minor deliverables that eventually culminate in the final creation. There is little in the way of independent tinkering because all of the modeling and Making is encapsulated within kits that the students purchase, but the creation element is still present. The instructor references that the students are "inventors" because they are creating something that is new to them. Even though this is a supportive/ mezzanine course it is essentially a project course in which the students are tasked to create a functional robot, and they must learn how to meet this goal by the end of the semester. Making and the creation of this artifact is a key component to the success of students in this course. There appears to be a high "overhead cost" in that the professor spends substantial time planning the semester projects.

Case B focuses on a sophomore level required course on statics and dynamics, and appears to not emphasize Making based techniques in the classroom. The objective of this course is to provide a foundation in the theory and principles of statics and dynamics. More specifically, it examines the following:

1. The effect of forces acting on particles and rigid bodies
2. Vector mechanics is used extensively
3. Equilibrium in two and three dimensions, to include distributed loads, trusses, and frames
4. Kinematics, including translating and rotating reference frames, and two-dimensional kinetics methods of force-acceleration, work-energy, and impulse-momentum

This course was taught in a less traditional manner, utilizing a "flipped classroom" approach. While the course did not embed explicit aspects of Making the instructor did attempt to proactively engage students. Students accessed recorded lectures prior to the class period, and the instructor used class time to have students work collaboratively to solve problems and work through challenges. The faculty member reported that student feedback was mixed in terms of their perceiving the value of using class time for problem solving as opposed to lectures. The interview data indicates that the instructor is skeptical of the value of Making for all courses, where some may benefit more than others.

Case C is a required mezzanine course that focuses on engineering statistics. The faculty member identified that students should be capable of doing the following upon course completion:

1. Use appropriate technique and software to formulate and solve engineering problems that require foundational statistics
2. Interpret the meaning of statistical tests/computations in ways that are useful for the appropriate decision maker
3. Articulate and defend the role of statistics in their engineering discipline and intended career

The professor stated that Making is important in this course because it makes statistics come to life. This course uses a competency-based assessment approach as well as integrates projects titled *Statically Significant*. This course focuses on traditional statistics, but with a unique approach in that it attempts to teach students the statistics is embedded in daily life and how it is more than just a tool for analysis. Through the *Statistically Significant* projects, the Making aspect is introduced. In an iterative and collaborative manner students work in teams and are tasked to create physical or media-focused artifacts that are intended to a provide context for understanding of practical statistics. These project artifacts range from creating a YouTube video, to building a catapult so large that it must be transported in the bed of a truck. The intent of the projects is to facilitate learning eleven core competencies: sample statistics, probability, hypothesis testing and confidence intervals, continuous distributions, discrete distributions, paired t-tests, regression, ANOVA, factorial experimental design, statistical tool selection, and the relevance of statistics. The students are left to the decision-making on what they create and how they go about it, but in the end the goal is for them to produce an artifact within the parameters of the assignment and before the project deadline.

Summary and Future Work

This work in progress paper provided an overview of the study, the frameworks used to guide the analysis, and a brief description of the preliminary analysis of the three case study faculty interviews. The details provided here serve to frame the study, and the preliminary findings suggest that the college experience and quality matters framework are viable frameworks for organizing and interpreting the data. Early findings suggest that elements of Making are utilized differently across courses, and more work is needed to fully analyze the faculty interviews with respect to the frameworks, and to explore how the case study artifacts align with the faculty member's reporting of the course through the interviews. Future work may also include observations of classes to better understand the context for what actually happens in the classroom.

References

1. Fairweather, J. (2008). *Linking evidence and promising practices in science, technology, engineering, and mathematics (STEM) undergraduate education: A status report for the National Academies National Research Council Board on Science Education.* Commissioned Paper for the National Academies Workshop: Evidence on Promising Practices in Undergraduate Science, Technology, Engineering, and Mathematics (STEM) Education, June 30.

2. Foster, C. H., Dickens, M., Jordan, S., & Lande, M. (2015). Learning from Toy Makers in the Field to Inform Teaching Engineering Design in the Classroom. *In Proceedings of the American Society for Engineering Education (ASEE) Annual Conference and Exposition* (p. 26.1070.1-26.1070.18). Seattle, WA: ASEE Conferences. https://doi.org/10.18260/p.24407

3. Heiman, A., Lande, M., & Jordan, S. (2015). What is Making? What is Engineering? *In Proceedings of the American Society for Engineering Education (ASEE) Annual Conference and Exposition* (p. 26.1726.1-26.1726.8). Seattle, WA: ASEE Conferences. https://doi.org/10.18260/p.25062

4. Lande, M., & Jordan, S. (2014). Making it together, locally: A Making community learning ecology in the Southwest USA. In *Proceedings of the IEEE Frontiers in Education (FIE) Conference.* Madrid, Spain.

5. Lande, M., Jordan, S., & Nelson, J. (2013). Defining Makers making: Emergent practice and emergent meaning. In *Proceedings of the American Society for Engineering Education (ASEE) Annual Conference & Exposition*. Atlanta, GA.

6. Oplinger, J., Heiman, A., Dickens, M., Foster, C. H., Jordan, S., & Lande, M. (2014). Making and engineering: Understanding similarities and differences. In *Proceedings of the American Society for Engineering Education (ASEE) Annual Conference and Exposition*. Indianapolis, IN.

7. Weiner, S., Lande, M., & Jordan, S. (2017). Making Identities: Understanding the factors that lead young adults to identify with the Maker Movement. In *Proceedings of the American Society for Engineering Education (ASEE) Annual Conference & Exposition*. Columbus, OH.

8. Jordan, S., & Lande, M. (2016). *Additive innovation in design thinking and making. International Journal of Engineering Education*, 32(3), 1438–1444.

9. National Academy of Engineering. (2004). *Educating the Engineer of 2020: Adapting engineering education to the new century.* Washington, D.C.: The National Academies Press.

10. Trilling, B., & Fadel, C. (2009). *21st century skills: Learning for life in our times.* San Francisco: Jossey-Bass.

11. Martin, L. Dixon, C., & Hagood, D. (2014). Distributed adaptations in youth making. *Proceedings of FabLearn 2014 Conference*, Stanford, CA, Oct 25-27.

12. Terenzini, P. T. & Reason, R. D. (2005). *Parsing the first year of college: A conceptual framework for studying college impacts on students.* Annual Meeting of the Association for the Study of Higher Education (ASHE), Philadelphia, PA, November 17-19.

13. *Quality Matters Rubric Workbook for Higher Education* (2nd ed.). (2011). Maryland Online, Inc. url: www.qmprogram.org

14. McKenna, A. F., Kremer, G., Okudan, E., Plumb, C., Ro, H. K., & Yin, A. (2011). Approaches to engaging students in engineering design and problem solving. *Proceedings of the American Society for Engineering Education (ASEE) Annual Conference*, Vancouver, B.C., June 26-29.

15. Yin, R. K. (2014). Case study research: design and methods. London: Sage Publication.