Physical Prototyping in the Makerspace for BME Students

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Abstract

Beginning with their first-year biomedical engineering (BME) course at the University of Illinois Chicago (UIC), students learn about and practice skills related to circuitry, programming, computer-aided design, and 3D printing, but have no curricular exposure to other forms of mechanical prototyping, such as a tooling or machining class. This limitation is apparent when senior students enroll in the capstone design class, as many teams don't have familiarity with appropriate material selection or basic fabrication techniques. Experience in physical prototyping prior to capstone design courses will allow teams to create better concept designs, preemptively identify challenges associated with fabrication, evolve physical prototypes, and develop improved verification tests, which are key deliverables in the two-semester course sequence. To address this deficiency, we piloted a new third-year course to introduce and provide practice in basic fabrication techniques that are useful for both capstone design and students' engineering competencies in general. Notably, this class also has the potential to address inequities that may exist within our student body. As the largest public university in Chicago, our BME program reflects great diversity. Some students, particularly those coming from well-resourced middle and high schools with pre-engineering classes or programs, have previous exposure to engineering design, design thinking, and prototyping. These students have more positive attitudes to engineering, increased familiarity with engineering topics, and enter the program with better engineering skills. Other students, from under-resourced schools, may not have prior exposure to (pre)engineering, design, or prototyping. Unfortunately, these students are disproportionately underrepresented minorities and/or from low-income families. The introduction of this physical prototyping class prior to capstone design courses will provide students exposure to multiple types of prototyping techniques in a structured course.

Challenge Statement

Students work independently to develop the same physical device – a toolbox – consistent with a set of design requirements. The toolbox will be constructed from wood, acrylic, textiles, and soft plastics. Various fabrication techniques using hand tools, power tools, and other equipment will be required to fabricate the toolbox, including measuring, cutting, sanding, joining, fastening, plastic molding, laser engraving/cutting, riveting.

With this unique course offering, we aim to strengthen the design experiences of our students by providing distinct opportunities to focus on various aspects of design throughout the curriculum. This prototyping course, part of a restructured design pipeline for student-driven innovation that includes an enhanced capstone design course, a summer problem-identification internship, and interdisciplinary collaboration with medical students, creates a structured format for student-driven innovation [1, 2]. We hypothesize that participating in the prototyping class will enhance student performance, student teaming, and design quality output in capstone design. Student participants will be tracked as they move into the capstone design to assess impact of the prototyping class on course outcomes.

While engineering principles have long been used in the diagnosis and treatment of human health, the field of biomedical engineering has evolved into a distinct discipline focused on developing technologies to advance healthcare and improve all aspects of human life. Biomedical engineers (BME) have broad training in engineering and life science fundamentals, including materials, electrical circuits, coding, thermodynamics, instrumentation, mechanics, physiology, biology, and chemistry. At UIC, all undergraduate BME students take courses in computer programming, microcontrollers, and instrumentation, but do not receive any formal training in mechanical design or fabrication. This imbalance is evident when students enroll in the senior design capstone course, a two-semester sequence, that challenges teams to design, build and test solutions to unmet clinical needs. Without prior experience using hand and power tools, measuring and cutting materials, mechanical joints, and molding, the capstone course is challenging because teams must both demonstrate proficiency in fabrication, but also iterate and evolve the design. Some teams are unable to iteratively improve their design as needed because they need to spend too much time learning how to safely use tools and other fabrication equipment for the first time. Teaching rapid prototyping techniques has been shown to significantly enhance students' experience with the design process [2-7]. To support students in gaining more exposure to prototyping techniques, we piloted the course "Physical Prototyping for Design" for BME students before they begin the senior design capstone course, anticipating that prior exposure to physical prototyping tools and techniques may improve outcomes in senior design, which often require teams to build electromechanical solutions for medical or healthcare needs.

Implementation

The Physical Prototyping for Design course was first offered in Fall 2022 and again in Fall 2023. Targeted at sophomore and juniors, this 3-credit hour course meets for 150 minutes each week at the College of Engineering's Makerspace, a hands-on learning environment that supports student coursework, design projects, student organizations, and faculty research needs utilizing additive and subtractive technologies, woodworking tools, machining and other equipment. Makerspaces are one way universities can provide additional hands-on experiences that support prototyping, and help develop students' design iteration and collaboration skills [3]. Since other courses in the BME curriculum emphasize the engineering design process and electronic prototyping, we decided this course would focus on providing exposure to using physical prototyping techniques for a common project - a personalized multi-level toolbox with fixed handle and an adjustable carrying strap with a soft polymer shoulder pad.

The course goals and learning outcomes for this course are:

1. Understand and adhere to safety precautions when using Makerspace tools.
2. Ability to select and use machine and hand tools depending on application.
3. Measure, plan and execute fabrication techniques for prototype development.

Enrollment is capped at 10 students, given the need for all students in the class to access necessary equipment in the Makerspace machine shop and woodworking shop. Over two semesters, 11 female students and 9 male students enrolled. Pre-course surveys for self-reported fabrication technique experience levels are shown below in Figure 1. 18 of 20 total participants over two semesters completed the survey. The survey, which included questions utilizing Likert scale responses (1-5), was granted an IRB exemption (STUDY2023-0423). On average, enrolled students had between little to some experience (2.46) with physical prototyping techniques.

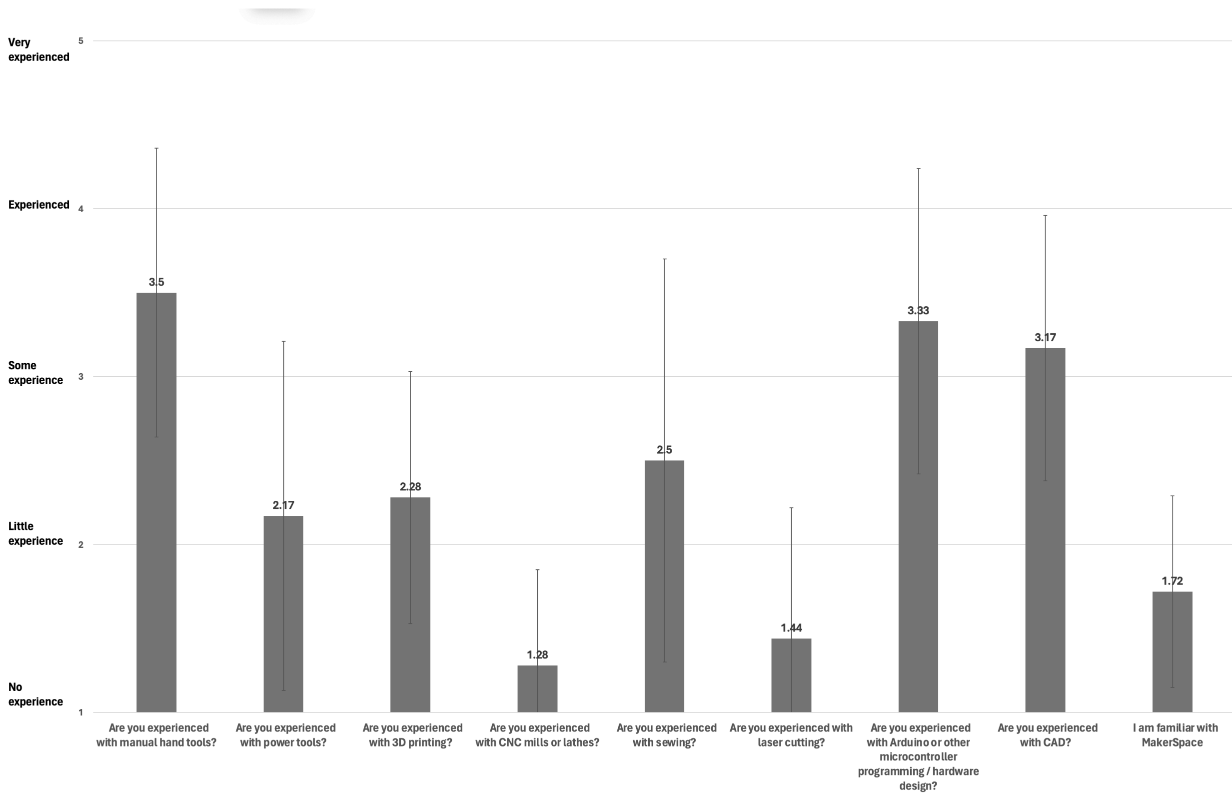

Figure 1: Pre-course experience levels for different prototyping techniques for BME 394: Physical Prototyping for Design. (n=18)

Students indicated the least experience (little to none) in using cnc mills, lathes (1.28) and laser cutting (1.44). Students indicated the most experience (some) using hand tools (3.50) and microcontrollers, such as Arduino (3.33).

At the beginning of class, students completed an online laboratory and equipment safety training module. As each piece of equipment was introduced, considerations for safe use were discussed and demonstrated. Topics in the course included:

1. Intro to fabrication tools
2. Working with wood, marking and measuring
3. Miter saw/router
4. G-Code for CNC router
5. Drill press
6. Jigsaw
7. Fasteners
8. Table saw
9. Clamping, gluing for assembly

10. Laser cutting
11. 3D printing for molds
12. Silicone molding
13. Wood finishing

The instructor used a standards-based grading (SBG) approach, where students must demonstrate proficiency of each learning outcome. SBG is an assessment method that purports to be a more holistic method of grading that evaluates how well students meet course learning outcomes directly using student work throughout the term rather than summative performance on separate assignments [9]. Using SBG, proficiency can change over the duration of the semester and students are able to demonstrate proficiency throughout the term, unlike using traditional grading methods where proficiency is measured at a specific moment in time (assignment due date, exam). This method also allows students multiple opportunities for reassessment until they demonstrate mastery.

Figure 2. Students in the Makerspace fabricating a multi-material toolbox.

Reflection

After piloting the course for two semesters, we have made the following observations. (1) The course was initially designed to be 50/50 lecture-lab, but we found that this did not leave sufficient working time for students to progress their projects in a timely manner. Lectures were reduced in duration, and some content was assigned as homework in preparation for subsequent classes. (2) Some students who struggled in the course necessitated a substantial number of outside-of-class sessions to stay apace. There was a wide variation in time-to-completion for each milestone; some students were able to finish early and some students required multiple attempts to complete each step. Time to completion did not correlate with previous experience levels; some students with limited previous experience demonstrated more facility with the hands-on activities, while others did not. (3) Using a standards-based grading approach was beneficial to allow students who needed more time to demonstrate proficiency, but required significantly more instructor time outside of class time.

A secondary goal of this course offering was to provide students with more exposure to the Makerspace facilities. Students are aware of the Makerspace but many do not take advantage of its services unless required to do so for classes. Students indicated low familiarity with the Makerspace (Figure 1: little to no familiarity, 1.72) although 14/18 of survey respondents (77.8%) reported that they have been to the Makerspace prior to enrolling in this class. We hope that increased familiarity with Makerspace will encourage more activity there, particularly for Senior Design, so students can benefit from its prototyping resources. Students expressed increased confidence and intention to utilize new knowledge for prototyping, although this was not explicitly surveyed.
Challenges in this course include scalability for increased enrollment and high levels of instructor-led outside class time. In subsequent course offerings, students will participate in pre/post surveys, so we can measure self-perceived changes in familiarity with prototyping techniques. In addition, we anticipate tracking student performance in Senior Design, comparing students who have taken this course with the overall class, to evaluate if there is an impact on number of iterations, number of prototyping techniques, and overall project designs.

References

[1] Felder, A. E., & Browne, M. G., & Kotche, M. (2023, June), *Board 5: WIP: An Interdisciplinary Project Development Pipeline Connecting Undergraduate Biomedical Engineering and Medicine Students* Paper presented at 2023 ASEE Annual Conference & Exposition, Baltimore , Maryland. 10.18260/1-2—42830

[2] Kotche, M., & Felder, A. E., & Browne, M. G., & Lynch, D. (2023, June), *Board 6: WIP: Development and Implementation of a Makerspace Class for BME Undergraduates to Enhance Skills in Senior Design* Paper presented at 2023 ASEE Annual Conference & Exposition, Baltimore , Maryland. 10.18260/1-2--42872

[3] Youmans, K., & Villanueva Alarcón, I., & Bouwma-Gearhart, J., & Nadelson, L. (2021, July), *Beyond Making: Application of Constructionist Learning Principles in Engineering Prototyping Centers* Paper presented at 2021 ASEE Virtual Annual Conference Content Access, Virtual Conference. 10.18260/1-2--36746

[4] Choi, Y. H., Bouwma-Gearhart, J., Lenhart, C. A., Villanueva, I., & Nadelson, L. S. (2021). *Student Development at the Boundaries: Makerspaces as Affordances for Engineering Students' Development.* Sustainability.

[5] Wigner, M. Lande, S. Jordan, *"How Can Maker Skills Fit in with Accreditation Demands for Undergraduate Engineering Programs*?" in 2016 ASEE Annual Conference and Exposition, New Orleans, Louisiana. June, 2016 doi:10.18260/p.25468.

[6] A. Longo, B. Yoder, R. C. Guerra, R. Tsanov, *"University Makerspaces: Characteristics and Impact on Student Success in Engineering and Engineering Technology Education,"* in 2017 ASEE Annual Conference & Exposition, Columbus, Ohio. June, 2017 doi:10.18260/1-2—29061

[7] Jariwala, A. S., & Wang, J., & Ferrarer, J. A., & Lonsberry, G. E., & Craig, K. L. (2020, June), *Interdisciplinary Mini-mester Course on Rapid Prototyping for Product Design* Paper presented at 2020 ASEE Virtual Annual Conference Content Access, Virtual Online. 10.18260/1-2—34863

[8] Jariwala, A, Spencer, T and Ferrarer, J.A., (2018, October), *"Design for Rapid Prototyping: A Review of Design for Additive Manufacturing Literature for Applications in Makerspaces"*, presented at Construct3D 2018, Atlanta, GA.

[9] Carberry, A. R., & Siniawski, M., & Atwood, S. A., & Diefes-Dux, H. A. (2016, June), *Best Practices for Using Standards-based Grading in Engineering Courses* Paper presented at 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana. 10.18260/p.26379