Board 6: WIP: Development and Implementation of a Makerspace Class for BME Undergraduates to Enhance Skills in Senior Design

Dr. Miiri Kotche, University of Illinois Chicago

Miiri Kotche is the Richard and Loan Hill Clinical Professor of Biomedical Engineering at the University of Illinois Chicago and currently serves as Associate Dean for Undergraduate Affairs in Engineering. Her research interests center on experiential learning, interdisciplinary collaboration, and promoting biomedical engineering through high school science teacher professional development.

Dr. Anthony E. Felder, The University of Illinois at Chicago

Anthony's current focus is on engineering education and its restructuring to better meet the diverse needs of students and industries. Anthony is also active in ophthalmology research for the multimodal imaging of retinal oxygenation and novel medical device design.

Dr. Michael Gordon Browne, University of Illinois at Chicago Department of Biomedical Engineering

Clinical Assistant Professor teaching engineering design, medical device quality and regulatory processes, innovation, and entrepreneurship to University of Illinois at Chicago Biomedical Engineering Students and Medical Students the University of Illinois College of Medicine Innovation Medicine Program. Research interests focus on the emulation of realistic medical device design in education and the quality assessment of educational design projects for between-project comparisons.

Dylan Lynch, The University of Illinois at Chicago

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Introduction:

The undergraduate curriculum in biomedical engineering at the University of Illinois Chicago emphasizes problem-based learning with a focus on as much hands-on project work as possible. To that end, our 100-level Introduction to BME course integrates CAD design, 3d printing and microprocessors to achieve learning outcomes. A 200-level course introduces team-based projects to explore design solutions to current clinical problems. In addition, all students are required to complete a lab-lecture sequence for bioinstrumentation and measurement. Students can take additional introductory and intermediate courses in 3d printing, open to all undergraduate engineering students. Combined, these courses provide a good foundation for electronic design using transducers and sensors for physiological and other input signals, as well as using various types of 3d printing for rapid prototyping. Students then build upon this foundation in their two-semester senior capstone design course, which provides an opportunity for teams to create, test and validate a prototype that addresses an unmet biomedical or health-related need. However, despite the emphasis on design-focused projects throughout the curriculum, students tend to have higher electronics/coding competency than in physical prototyping skills.

Because it is a convenient way to quickly have a physical product in hand, many students feel most comfortable with designing prototype components that are 3d printed, without consideration to other types of fabrication. This limitation is apparent in our senior design (SD) classes, as many teams don't have familiarity with appropriate material selection or basic fabrication techniques. It has been reported that it may be the *majority* of engineering students who do not have prior shop fabrication experience [1]. When students reach their capstone courses, not only are they unfamiliar or unaware of prototyping tools, it forces instructors to allocate time for individual instruction and guidance on appropriate techniques for their project rather than on design specifications and product requirements [2]. In Fall 2023, recognizing this limitation, we piloted a Physical Prototyping for Design course, with the goal to increase familiarity working with various materials, power tools, and machining techniques. As others have reported [3], we expect early exposure will ultimately allow students to bring this experience into SD to create better concept designs, preemptively identify challenges associated with fabrication, evolve physical prototypes, and develop improved verification tests.

Methods:

In fall 2022, we offered a one semester pilot course "Physical Prototyping for Design" aimed at sophomore and junior students. This 3 credit-hour course, held in our Makerspace, was split into a lecture and lab session, each meeting once a week for 75 minutes. Course learning outcomes for this class are: 1) understanding of prototyping tools and techniques, 2) proficiency in use of hand and power tools, 3) understanding of materials characteristics, such as wood, soft plastics, fabric, and metal, and 4) knowledge of safety procedures and protocols for using prototyping equipment.

At the beginning of the semester, a pre-class survey was administered to the ten students enrolled to evaluate self-reported experience with various types of fabrication equipment.

Table 1: Experience Levels with Prototyping Equipment. Likert scale: 1 (no experience), 2 (little experience), 3 (some experience), 4 (experienced), 5 (very experienced)	
Manual hand tools (screwdrivers, hammer, wrench, pliers, clamps, saws, etc.)?	3.70 ± 0.82
Power tools (table/circular/band/miter saws, drill press, jigsaw, router, etc.)	2.30 ± 1.25
3D printing?	2.40 ± 0.70
CNC mills or lathes?	1.40 ± 0.70
Sewing?	3.00 ± 1.25
Laser cutting?	1.30 ± 0.67
Arduino or other microcontroller programming / hardware design?	3.20 ± 0.92
CAD (Solidworks, AutoCAD, Fusion, Creo, Google Sketchup, etc.)	2.90 ± 0.63
I am familiar with MakerSpace	3.80 ± 0.63

The course project during lab sessions focused on fabricating a wooden box, including a handle, canvas carrying strap and shoulder pad, and an acrylic shelf. Tools and techniques that were introduced in the class include: measuring, marking, cutting (table saw, bandsaw, jigsaw, miter saw), drilling (power drill, drill press), finishing edges (router, hand), adhesives, fasteners (nails, screws, rivets), CNC (programming G-code), and molding of soft polymers.

The non-lab portion of the class included discussion topics and activities related to safety training, material properties and selection for various applications, introduction to hand and power tools, wood (types, selection and cuts), estimation of material and costs, reverse engineering of various products and how chronological order of fabrication and assembly, types and applications of fasteners, and use of G-code.

We expect that firsthand exposure to enhanced prototyping methods will yield more diverse and improved prototypes in SD. Students will be tracked as they progress into the Senior Design course. At the end of the Fall semester, SD teams are expected to complete a first iteration of a "low-fidelity" prototype. Each low-fi prototype will be evaluated for the number of techniques and tools that students are exposed to in the Physical Prototyping for Design course, and a comparison between teams that are comprised of any students enrolled in the previous course will be compared to teams that do not. Final prototypes at the end of the Spring semester will similarly be evaluated in this way.

Discussion:

While students report on average *little to some* experience in various prototyping techniques, there was wide variability among the small group. In actuality, those with experience had limited previous exposure, and most were unaware of safety considerations or what constituted proper usage. Students exhibited high variability in achieving set tasks each class period, and at least two students came to the Makerspace outside of class time to keep pace with class progress. One challenge that we experienced was the balance of allowing students to make a mistake requiring new materials and additional time with the opportunity to learn from the mistake. For example, one student did not appropriately account for tolerances repeatedly, and despite warnings, saw quickly that the parts did not fit together.

Each student fabricated a wooden box that incorporated multiple fabrication techniques that were unfamiliar to the students before the class. Each student completed the work to a satisfactory degree. Two students regularly came to the Makerspace, where the course was held, outside of class hours to ensure completion. As a pilot course, students were allowed to use as much time as needed to satisfactorily complete course requirements. Course evaluations were collected from six students, which indicated a positive learning experience: 5/5 (0 Std Dev) instructor's overall teaching effectiveness, 5/5 (0 SD) overall quality of the course, and 5/5 (0 SD) alignment between course assignment and content/emphasis.

Several free response comments were also collected from the course evaluation, as bulleted below.

- "I enjoyed this course!! It was educational to know about prototyping/fabrication of the product. I loved that this class had one day of the workshop and one day of the lecture. The professor was very kind and encouraging toward all students."
- I loved how enthusiastic professor [X] was. I learned how to use a variety of tools that will definitely carry over to different areas in my life, such as home or work. It was great learning these skills because now I feel like I can build my own things with wood and find the proper tools. This is a great skill that all engineers should have."
- "Having a class that allowed the students to learn how tools worked was helpful."

As a new class, we wanted to make sure we had a sufficient number of enrolled students. Despite targeting sophomore and junior students, several of the students who enrolled were concurrently enrolled in SD. While this precludes us from tracking the impact of this course on their subsequent senior design projects, we felt that running a full pilot course would be beneficial in refining subsequent offerings, rather than cancelling the course due to insufficient enrollment. However, after one semester, we have sufficient interest for the next offering such that we will limit the course to those who are not yet in senior design.

We recognize that the evaluation of the impact of this course on SD outcomes has limitations. Students who have participated in the Physical Prototyping for Design may end up on teams with projects that may not benefit from tools and machining equipment. Teams may identify a strong concept solution early on and tracking the number of prototyping tools/techniques may not appropriately represent a successful outcome. Nevertheless, formal exposure to additional prototyping methods benefits students. With future support pending, we hope to methodically evaluate the effect of this course in SD by assessing improvements in (1) quality of low-fidelity prototypes early in the semester, (2) evolution of design from low to high fidelity prototypes as teams iterate, (3) number of fabrication techniques and (4) quality of final prototypes at the end of the term.

Finally, this pilot course is part of a larger curricular effort to strengthen design skills for our students, culminating in SD. These initial efforts emphasize identifying clinical problems and concept generation from interdisciplinary collaborations between students in Medicine and Engineering, so that strong projects with true clinical relevance have continuity beyond Senior Design. Ensuring BME students have increased experience with a variety of prototyping techniques is a foundational requirement for programmatic success.

References:

[1] Hamburg, Shanti D. "Flipped Lab: Introduction to Prototyping & Manufacturing Scalable Instruction in Making." *IJAMM*(2020).

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[3] Cook, T. V., & Lyle, J. A., & Kerestes, R. J. (2018, June), *Board 73 : Work in Progress: Reinforcement of Engineering Education with Hands-on Learning of Technical Skills* Paper presented at 2018 ASEE Annual Conference & Exposition , Salt Lake City, Utah. 10.18260/1-2--30097