Physical Computing Design Project to Promote Equity and Community in an Introductory Engineering Course

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Prior to matriculation, first year engineering students at UC Davis, a large public university, declare majors in one of the eight academic departments offering undergraduate degrees. Given the general lack of hands-on design experiences in lower division coursework across the College of Engineering (COE) departments and the need for an oral communication elective prior to senior year, the *Introduction to Engineering* elective was piloted in Fall 2016.

The 4-unit active-learning project-based course was targeted towards lower division engineering students across all majors with emphasis on oral communication skills through a hands-on team-based design project. Communication and engineering design content was delivered in the twice weekly larger lecture sessions where discussion and reflective activities where emphasized. Hands-on design and team-based activities were facilitated during the weekly studio sessions for up to 24 students in a classroom retrofitted specifically for the course. Studio space was equipped with movable workbenches, storage space for design resources, several mobile erasable partitions, projectors and wall-mounted smart boards to support collaboration and a variety of technical presentation formats.

With the aim of improving student engagement and retention, a dedicated instructor was hired to innovate and grow the course to serve all first year students in the COE (approx. 700 in 2018-19). Of the total 144 students enrolled in the course in fall 2018, 39% were freshman, 38% sophomores, 19% juniors and 5% were seniors. Among the freshmen, 51% declared electrical engineering as their major, 32% were mechanical, 22% were civil, 17% were aerospace, 17% computer followed by 8% biological systems, 4% biomedical, 2% computer science and 2% material science; 31% identified as female.

The “Physical Computing Design Solutions for Farmers” project was conceived as part of the curriculum enhancement efforts. The self-sustaining campus-based student farm served as a design client for students to explore a practical and authentic problem space, to interact with staff, to receive feedback on design concepts and to test their prototypes.

“Physical Computing Design Solutions for Farmers” project was structured around a series of communication milestones leading to a Final Design Showcase event where, in lieu of a final exam, the multidisciplinary teams presented their functional prototypes to invited university-affiliated guests (e.g. farm personnel, alumni, faculty, graduate students, university staff, etc.) who provided evaluation and feedback.

The open-ended team-based project was structured to provide all students an opportunity to tinker with, to learn and to apply open-source digital technologies (e.g., Arduino, Raspberry Pi, electronic circuits, etc.) in order to create proof of concept prototypes for the Final Design Showcase. Interested students were offered training on and use of 3D printers and a laser cutter. Prior student experiences with these technologies was not required. Student knowledge of technology skills was *not* graded at any point in the course. Teaching and learning of the digital technologies and other prototyping tools were conducted through a collaborative, learner-centered and community-based approach.

TAs delivered guided instruction on the general use of open-source technologies in the mandatory studio sessions at the beginning of the academic quarter. Additional TA support was offered weekly during the optional open studio sessions. To enable tinkering and making activities outside of the classroom, all teams were provided with a take-home technology kit for learning and creating prototypes (e.g., Arduino, Raspberry Pi, sensors, LCD screens, rechargeable batteries, etc.). Students were encouraged to work with their peers and to utilize a range of freely available resources such as internet sites, YouTube videos, on-line discussion boards, project sites, library books, etc.

Tinkering has been defined as a type of making that sits on the more creative and improvisational continuum where things could fail in unexpected and sometimes wonderful ways [1]. This approach relies on materials, phenomena and models to inspire ideas along with a collaborative culture of facilitators and fellow tinkers to support learners in realizing their ideas [2]. A learning dimensions framework for Making and Tinkering developed by the Exploratorium [3] provided guidance and structure to the “tinkering” instructional initiative for this project. Although the framework was generated with K-12 informal learning experiences in mind, it offers a promising pedagogical approach for undergraduate engineering education. The five Learning Dimensions (LD) of Making and Tinkering are:

LD #1 Initiative and Intentionality: active participation, setting goals, taking intellectual and creative risks, adjusting goals based on physical feedback and evidence.

LD #2 Problem Solving and Critical Thinking: trouble shooting through iterations, dissecting components, seeking ideas tools and materials to solve the problem, developing workarounds.

LD #3 Conceptual Understanding: making observations, asking questions, testing tentative ideas, constructing explanations and applying solutions to new ideas.

LD #4 Creativity and Self-Expression: playfully exploring, responding analytically to materials and phenomena, connecting projects to personal interests and experiences, using materials in novel ways.

LD #5 Social and Emotional Engagement: working in teams, teaching and helping one another, expressing pride and ownership, documenting/sharing ideas with others.

Early efforts to understand student’s experiences with the tinkering and prototyping activities relied on written student reflection and direct feedback. Lecture handouts were an integral part of the curriculum, providing opportunities for students to reflect on their communication, teamwork and design learning. Evaluation on an end of quarter in-class student reflection assignment intended to help prepare students for their final design showcase presentation provided valuable insight into preliminary outcomes of the “tinkering” teaching and learning approach. Of the freshman students who completed the reflection handout (n = 53) several had little to no prior experience with Arduinos (84%), Raspberry Pi (94%), electronics (86%) and/or coding (86%).

Given the open-ended nature of the assignment and pervasive lack of prior experiences with the technologies, instructors had concerns about student engagement during the prototyping process. Prior research on the role of challenge in student’s intrinsic motivation and engagement were particularly relevant to understanding student’s experience with the open-ended assignment [4, 5].To determine student’s perception of their team project’s challenge level, the following item was included in the lecture handout:

In your view, *how risky or challenging* was your team's design project? Select one of the options below that best matches your experience with the design project.

☐ It was easy. *I felt comfortable knowing we could get this done.*

☐ It was somewhat challenging. *I felt a bit out of my comfort zone but hopeful it would work out*.

☐ It was challenging. *I was not sure we could do it and a bit concerned it would all come together.*

☐ It was very risky**.** *I thought we were in way over our heads and not sure it would actually work.*

☐ Other (please share if you had another view)

Results of student responses in Figure 1 indicated that the freshman students overall perceived the design project assignment as challenging (96 %) with many (54%) feeling out of their comfort zone or not sure it would all come together (42%) by the final design showcase.

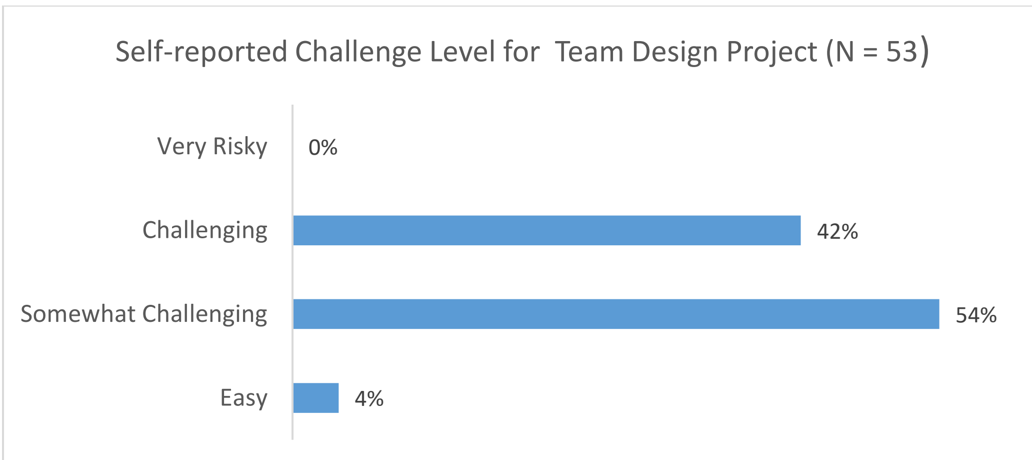

Figure 1. Freshmen results for challenge level of team design project in fall 2018.

Further examination of student's responses on the end of quarter lecture handout were insightful. Student responses to the prompt "Where and/or from whom did you see support while learning these new things?" included primarily asking their TAs (95%), using a variety of internet sources (66%) including forums, videos and websites, and/or asking teammates, classmates or friends (15%). In response to failure and/or challenge the team faced during the design project process, students talked about changing their project scope, direction and solution based on lack of experience, time constrains, difficulties with teamwork and the desire to do something unique.

Survey responses and project outcomes are encouraging for bringing "tinkering" experiences into the undergraduate engineering curriculum to promote equity. By providing supportive instructors (TAs) and free access to a variety of prototyping tools (Arduinos, Raspberry Pi, 3D printing, laser cutting, electronics and coding), the freshman students had opportunities to explore, to collaborate, to be creative and to connect with a much broader community. Further research on how these experiences influence student's sense of belonging to a post-secondary academic community along with their self-concept as engineers, problem-solvers and designers would be beneficial.

References

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