Engagement in Practice: Practicing Empathy in Engineering for the Community Course

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This Engagement in Practice paper describes the course sequence of a service-based engineering projects course that focuses on humanitarian projects for local clients. The course successfully incorporates both technical skills and professional skills goals, including building a set of hands-on engineering skills for prototyping and manufacturing and understanding the role of analysis in the design process as well as learning and practicing effective teamwork skills and understanding the importance of an ethical code for the practice of engineering. The authors reveal specific examples of client projects, lessons on how to pair students with clients, lessons learned after several offerings of the course, transferability to other settings, and opportunities for future improvements to the course. This course description adds to the growing base of available offerings for service-based, active learning courses.

Introduction

During spring 2014, the Engineering Plus undergraduate program at the University of Colorado Boulder piloted an innovative engineering design course available to students in all engineering disciplines (link to course site, including examples of student projects: https://www.colorado.edu/eplus/courses/geen-2400-engineering-projects-community). The purpose of this course is to provide engineering students with the next step in a sequence of hands-on, team-based, interdisciplinary engineering design courses and create a natural progression between a first-year projects course and senior capstone course. The University already offers an entrepreneurial design course option for juniors but the second-year of coursework was lacking a related course option. Based on research around project-based service learning that incorporates real clients, the Engineering for the Community (EFC) course was born.

The EFC course emphasizes humanitarian engineering and integrated systems with electrical, mechanical and software components to provide our students with practice in multiple foundational areas valuable for their subsequent coursework — including the required senior capstone courses — as well as participation in the engineering workforce. Course expectations challenge students to take first-year design projects to a deeper dive into the design process by incorporating empathy through engaged user-testing and considering the robustness necessary for public-use products.

Collaborative student teams design engineering products for local community clients. Clients are largely non-for-profit community organizations or members and range from local fire fighters, K-12 teachers, hospitals, and local farmers to people with disabilities or special needs. As the course evolves in service of the local community, the list of clients grows. Most recently, several engineering students in the course have sought their own clients based on personal interest and graduates of the course have returned as clients for their entrepreneurial- and humanitarian centric-startups.

Background

Similar to other universities, CU Boulder has long-offered a first-year projects class, described through previous research, that brings students from different disciplines, ethnicities, genders, and backgrounds together through a semester-long, team-based design project [1], [2]. The semester-long projects for the course are traditionally chosen by individual professors, and topics range from assistive technology projects with actual clients to water filtration systems for developing countries, among others. First year engineering undergraduate students spend the semester learning about the design process by working on teams to produce a tangible final project, culminating with an Engineering Design Expo at the end of the semester. Several engineering departments require this course for first-year students, including mechanical, civil, environmental, and aerospace engineering.

Further research from this team and others around service-based projects suggests that students in actual client-based projects out-gain their peers in non-service sections with respect to academic learning of core material. These studies contend that engagement with service-based project clients can provide participants with a deeper understanding of the social context of their work, increasing technical, professional, and interpersonal skills, ultimately offering engineering undergraduate students a context for increased buy-in and learning during the course [3], [4], [5], [6].

Initially, the faculty used this research to infuse more client-based projects into the first-year course. However, a new need arose around the design of an additional projects course to fill the gap between the existing first-year course and the junior-level entrepreneurial design course option already offered. Engineering faculty noticed that the second-year of engineering coursework was very theory-predominant and lacking a related design projects course option. Based on research and experience with service-based project clients, the Engineering for the Community (EFC) course was proposed and developed to intentionally expand valuable professional and technical skills of engineering students in a client-based context and fill the need for a sophomore-level projects course in the design sequence of courses.

Course Outcomes and Grading

As stated, the main purpose of this course is to provide engineering students with the next course in a sequence of courses in hands-on, team-based, interdisciplinary engineering design with a focus on humanitarian and service-based engineering. Course goals include applying the iterative design process to improve a design for a local client, practice effective teamwork and conflict resolutions skills, develop and practice professional communication skills with a community client, effectively apply technical skills to produce prototypes and design artifacts, and consider an ethical process that will yield appropriate decisions when needed in working with design in service of individuals. Course expectations challenge students to take design projects to a higher level by requiring an additional iteration through the design cycle and more engaged user-testing—in order to infuse student projects with the robustness necessary for public-use products. In addition, course outcomes incorporate successful team dynamics, individual skills development, and multiple opportunities for self-reflection of steps of the design process.

Courses involving collaborative design teams — and grades that are dependent on the associated team deliverables and final project — can be frustrating to individuals placed on teams that do not perform to their expectations. The EFC course grades have a team-based set of graded components;

half of students' final grade is set by team projects deliverables. However, individual course elements have been included throughout the semester to allow students more input into their final grade. These elements include personal reflections on skills development, user testing, and ethical considerations of their design for public-use products. Each student peer evaluates their team members several times over the semester using a homegrown "bonus dollars" online evaluation tool (See Appendix A for EFC Peer Evaluation Tool), and each evaluation is followed by individual student meetings with the instructional team around what is working and opportunities for growth. At the conclusion of the semester, teams are graded on their presentation of the final project at a public Design Expo, a final technical report, and successful delivery of their product to their client for use in a public setting.

Course Execution

The logistics of the EFC course reflect already established first-year projects and junior-level innovation courses in the literature [7]. Some similarities include size of teams and practice of major design deliverables. However, this course takes successful elements from multiple project based courses and weaves them together into a cohesive and meaningful service-based course for students. These logistics are described in this section.

The EFC course is designed as a sophomore-level course, with a first-year projects course as a prerequisite. It is required only by students in our design-focus engineering degree program; however, upper-level and transfer students often take this course as a substitute course for the first-year projects requirement by their departments. The course includes one lecture period and two lab periods for a total of 5 contact hours per week, though students report that they spend an average of 10+ hours per week on this class. The course is also held in a project-compatible classroom, with collaborative tables, space to store projects, and close access to staff and facilities, including a manufacturing center, wood shop, electronics testing/fabrication center, and prototyping equipment (e.g., laser cutters, 3D printers, and sewing machines) instead of a traditional lecture hall (link to resources centers on-site here: https://itll.colorado.edu/centers/). Each section of the EFC course utilizes outside support from two Teaching Assistants (specifically chosen for their prior experience in the course with machining and electronics), as well as the knowledgeable staff engineers and student-staff who run the manufacturing, electronics, and prototyping centers, allowing for multiple resources for student support to work on their client projects outside of class time.

As a team-based projects course, each student in EFC is placed into a team of 4-6 students to complete the semester-long project. Each section has a capped enrollment of 30 students, or approximately six teams per section. Throughout the course, students engage in an introductory team building activity, a major client-based design project, several out-of-class skills workshops centered around machining and electronics (described below), guest lectures/workshops, and a final Design Expo.

In order to maximize the effectiveness of each team, students complete a social styles assessment in the first week based on individuals' observable patterns of behavior when interacting with others [2], [8]. The instructor of the EFC course uses the social styles assessment results to ensure the teams are balanced between communication styles. The introductory team building activity allows the students to bond with their team while they complete a scavenger hunt to locate the different

resources available to them around the building. After the introductory assignment, the students work in their teams to complete their major design project where they perform entrepreneurial design work to create affordable innovations that encourage health, wellness, and/or safety for people in need in communities throughout the State. In lieu of a textbook, each student is expected to contribute $75 to their teams' major design project for prototyping materials and workshop expenses. Each team is matched with a client or has the option to seek out a client with whom they are interested in working. Throughout the main design project, students gain experience in working with an external partner and developing a dynamic professional relationship.

Successful completion of a first year projects course is a prerequisite for the EFC course, and, as there are multiple offerings of first-year courses, students come into EFC with varying technical and professional skills and abilities. Thus, the students are required to attend at least three advanced workshops in machining or electronics outside of class time to expand their technical prototyping skills set. The completion of the workshops is intentionally required midway through the semester to bolster students' ability to incorporate their new knowledge into their major design project.

Guest lectures are also held throughout the course by local industry professionals and other university faculty to provide students with specific research and skills to help with their projects. Milestone deliverables throughout the semester keep each project team on track, as well as provide growth opportunities in public speaking. The students initially present a preliminary design review (PDR) to their peers, instructional team, and resident engineers to receive feedback on their design. They then prototype and thoroughly develop their design for several weeks following the PDR and present their critical design review (CDR). A generalized timeline is provided in Appendix B.

Each student team is expected to have a functional project leading into the Engineering Design Expo held at the end of the semester. The Design Expo provides the opportunity for 100-200 engineering project teams per semester to present their work to both industry judges and the public. Local industry professionals provide invaluable feedback about the design and the opportunity for the team to present to an external source. There are several awards given out based on the judges scores and the public votes.

Client Partnership Development

At CU Boulder, instructors have taken multiple approaches to developing client partnerships. Starting within the Instructor's personal network, teachers, fire-fighters, nurses and occupational therapists, etc. make good points of contact for potential clients. Posting a call for clients on public social media groups like Facebook and Reddit can be an effective way to reach potential clients in the community outside the instructor's personal network. In addition, cold-calling local schools, fire departments, animal shelters, etc. can be a fruitful, albeit time-consuming method of finding clients.

Because this process is time-consuming, and utilizes critical engineering skills in human centered design, Instructors have piloted having the students reach out to community organizations to find their own clients. This compresses the class schedule, but has resulted in a more diverse client base and some positive chemistry between student teams and their clients. In addition, it helps the students practice open-ended thinking and empathy when making a first contact with a potential client. Once the course has been running for a few semesters, some clients will hear of the course via word of mouth and approach CU Boulder projects-course faculty with project ideas.

Whether the professor or students find the client, a critical role of the course instructor is helping the students develop a realistic project scope, and briefing the clients with clear expectations of what to expect from the course outcome. The key outcome of this course is student learning, not a successful project. Most projects are not suitable for client use after just a few months of development by second-year engineering students, and the instructor must work with the client to set realistic expectations on this front. Even if the client is disappointed by the student's work, they must be prepared to respond positively and constructively to the student.

Successes and Lessons Learned

Over the past six years of implementation, the EFC course has evolved based on both student and faculty input. Some changes include: moving content lectures to early in the semester to allow more time to focus on product development, more frequent required client check-ins, development of team websites for communication, required team project timeline and team member responsibilities (including "next steps" at each deliverable), emphasis of student "experts" to help each other from other teams, incorporation of student reflection on improvements (how design is different from their original idea) and risk (what is outside their comfort zone) at each project deliverable. Based on end-of-semester course feedback and focus groups, these additions have helped make the course more valuable for the students and also more reflective of professional workforce experiences. In the focus group results over the past three years, 97-100% of students have valued having a course focus on local clients with a real-world application, 77-92% of students specifically enjoyed their client interactions, and 94% of students liked learning how to communicate with a client.

Most recently, several engineering students in the course have sought their own clients based on personal interest and graduates of the course have returned as clients for their entrepreneurial - and humanitarian centric - startups. This has led to the need for more intentional discussion on scope creep, especially in their presentations and final report.

There are many success stories from the EFC course as well. At least three teams from the course have started the patent process based on their work during the semester. One critical lesson is to talk with teams that might wish to patent their work before the team presents their work to the public (e.g., the end of semester Engineering Expo). Public presentation is a critical milestone in the patent timeline, and could hamper their ability to get a patent on their project. Also, several graduates of the course who are now starting companies of their own have recently returned as clients, working with undergraduate students to help design components of their current entrepreneurial ventures. As an example, two of our former team projects have rolled into companies of the students once they graduated.

One truly disappointing story from the course was when the client, a local food-truck vendor, disagreed with the direction of a student project. Instead of responding productively, the client ghosted the students: Stopped replying to emails and ignored phone calls. In this scenario, the instructor stepped in to try to resolve things with the client, and eventually the instructor put on the hat of the client and direct the group through the rest of the semester. While the students had a positive experience in the design process, this situation underscores the need for the instructor to vet and brief clients to have appropriate expectations.

Conclusions and Transferability

Providing engineering students with a four-year sequence of hands-on, team-based, interdisciplinary engineering design courses starting their first year through their senior capstone allows them multiple opportunities to add to their technical and professional skill sets. Faculty at the University of Colorado Boulder found the second-year of traditional engineering undergraduate coursework lacking in a suitable multidisciplinary design projects course and developed a new course based on research around project-based service learning that incorporates real clients.

The Engineering for the Community (EFC) course has been a positive experience for students and a good connection between the University and the local community. This is exemplified by the startups and patents that have been produced by the course, as well as the number of return clients that participate and the word-of-mouth growth of the program. Specifically, over 95% of clients rate the experience positively (only ever had 3 not) and understand that limited time and resources result in more prototypes than robust public use products.

When transferring this course to a new college or university, it is important to consider the infrastructure support that can be offered to the students. At CU Boulder, students have access to staff and facilities (as described above in Course Execution). These facilities help improve the quality of the final product, and provide the opportunity for students to work on projects outside of scheduled laboratory time. Students self report working an average of 10-12 hours/week based on Faculty Course Questionnaires, with only 5 hours/week being contact hours with the instructor. Because the students turn over their projects to clients, a certain level of project quality and professionalism is required. This makes the course ideal for students who have already completed a first-year projects course or transfer students who are further along in their studies, but not a great fit for first-year students.

Projects courses should be dynamic, and evolve based on student, client, and instructor feedback. Future improvements to this course could include a website highlighting the course, past projects, and a way to help potential clients properly scope projects and pair with student teams. Students also have voiced a desire to form cross-team collaborations and leverage the strengths of their peers on other teams. We see this as an opportunity for students to make connections between diverse skill-sets and final product capabilities, but need to balance this with students getting out of their comfort zones and learning new and foreign skills. An ongoing need for the EFC course is to offer multiple measures for students on dealing with difficult teammates or clients, while maintaining professionalism and cultural sensitivity. Lastly, based on the extreme popularity of the course, offering a way for juniors and seniors to receive elective credit for participating in EFC would be beneficial for students across our college.

The EFC course has met the need for a sophomore-level design projects course to continue the design engineering education of students between their first year of undergraduate studies and junior or senior year courses, such as entrepreneurship and senior capstone. The sequence and logistics of the course are transferable to other universities who desire to create a client-based design projects course in their own continuum of hands-on design courses for students.

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Appendix A - EFC Peer Evaluation Tool

This online tool is used midterm and final weeks of semester. Bonus dollars received are averaged for each team member and converted to a grade as well as used for discussion.

Your team has been awarded a(n imaginary) $1,000 bonus for your outstanding work on your project. YOU must decide how the bonus will be allocated. Distribute the $1k among your team members, including yourself. Take into consideration time commitment, special contributions, leadership, unique skills, etc. Provide a rationale for your allocations.

Team Member	**Bonus Amount**	**Rationale**
Total	**$1,000**	

Appendix B - Generalized timeline for 16-week EFC projects course

Milestone	Deliverable	Deadline
Preliminary Design Review	Formal oral presentation covering problem statement, specifications, and preliminary design ideas.	Week 4
Prototype	Mock-up or prototype due. Must demonstrate functionality. Informal presentation.	Week 7
Peer Evaluation	Team individuals submit detailed written evaluations of their teammate's contribution to the project.	Week 9
Critical Design Review	Formal oral presentation of selected design concept. Include evaluation of alternatives, mock-up & description of selected design, preliminary materials, cost estimates, and production requirements.	Week 10
Software Check	Informal check of program code.	Week 11
Functional Project	Demonstration of design solution. Focus on completed hardware. Exposition format.	Week 12
Poster Presentation	Short presentations of posters for design expo.	Week 15 (Early)
Design Expo	Functioning final project and poster presentation of design process to industry judges and the public. 9 AM - 4PM.	Week 15 (Late)
Final Design Report	Written report documenting specifications, alternatives considered, description, analysis, evaluation, cost analysis, and recommendations.	Week 16
Peer Evaluation	Team individuals submit detailed written evaluations of their teammate's contribution to the project.	Week 16
Project Client Signoff	Client acknowledges receipt of the final project.	Week 16