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Drones for Good: Interdisciplinary Project-Based Learning Between Engineering and Peace Studies*

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Engineering practice is inherently interdisciplinary. Current curricular structures, however, provide engineering students with few opportunities to work across disciplinary boundaries. In this article we report on a project-based course where students from a School of Engineering and a School of Peace Studies were brought together to design a drone that would have a positive impact on society. The course learning objectives focused on students' abilities in relationship to broader contextual issues (process), a bounded technical challenge and its social implications (project), and their role in the process (reflection). A key goal for the course was to help students recognize how their disciplinary identity shapes the way they approach problems and to recognize the value of perspectives from other disciplines. We present an analysis of both qualitative and quantitative data to explore whether the course met these objectives and to reflect on the opportunities and challenges such a class provided for our students. We determine that we have developed the basis of a promising model for engaging students from multiple schools and background and we conclude by proposing future scholarship.

Keywords: multidisciplinary design; interdisciplinary; communication skills; drones; peace studies; robotics; UAV; UAS

1. Introduction

At the University of San Diego we are working on a multi-year project to develop what we call "Change-making" Engineers [1–11]. Funded by a National Science Foundation (NSF) Revolutionizing Engineering and Computer Science Departments (RED) grant, this project involves efforts to produce program graduates who are capable of improving society by practicing engineering with attention to sustainability, humanitarianism, and peace and social justice. The School of Engineering is developing a curriculum that directly integrates these themes into engineering courses to help our students understand the profound social responsibility engineers hold in shaping society and to equip them to meet the challenges that they will face in their professional roles.

In Fall 2017 we offered "Engineering Peace," our first new course developed to achieve these goals. This project-based course challenged interdisciplinary teams of students from the School of Engineering and the School of Peace to design a drone[1] that could be used to make a positive impact on society. As students confronted how complex the apparently-simple goal of "having a positive impact on society" could be [12], they collaboratively built a small drone using inexpensive technology and open source software. We decided to focus the course on drones because they represent a combination of technical and ethical provocations that would require students from both schools to engage with unfamiliar questions and develop new skills.

We developed this course in the context of a number of critical assumptions about the impact that it could have in our students' lives. First, we think there is a strong benefit for students in gaining concrete skills and tools that they can use in the future, either outside of their area of disciplinary expertise or in collaborations with others who do not share their backgrounds. We wanted a class where students could develop collaboration as a professional skill, as we hear constantly from employers that communication and teamwork are some of the most critical skills for recent graduates to possess [13, 14]. Our conviction that collaboration across disciplinary background should be approached as a professional skill led us to require that all our students take an online module about pitching their ideas to investors.

Second, we understand that there can be real impediments to collaboration across disciplines. Students often develop stereotypes during their

[1] We have used the term *drone* throughout this article, despite this being a term of art. Unmanned Aerial Vehicles (UAVs), Unmanned Aerial Systems (UAS), and Remotely Piloted Aircraft Systems (RPAS) are more technically precise terms, and are preferred by specialists in a number of fields. The American military, for example, prefers RPAS, as it emphasizes the piloted nature of the flight, and thereby the flight's conformity to extant international rules.

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training. These stereotypes may be reductive or dismissive of other ways of thinking. These stereotypes can limit their ability to work respectfully and productively with others and to take advantage of the opportunities that disciplinary diversity presents [15–17]. Following the contact hypothesis [18] and in light of our understanding that the skills and insights that students develop on their own are some of the most powerful, we designed this course to reduce stereotyping by exposing them to real people and alternative disciplinary approaches to problem solving in real time. Readers will note that our choices in this course reflect our personal and institutional commitments. Other educators are encouraged to draw on our insights to build courses that pivot around diverse obligations and interests.

In this paper, we provide a brief review of interdisciplinary courses on drones on offer within the United States. We then report on our pedagogical approach for the course, examining whether and how student learning was enhanced in a course co-taught by faculty from two very different Schools in the University. Based on our experience, we offer insights for others interested in developing similar courses at their own institutions. We describe a successful approach for contributing to engineering education that is explicitly sociotechnical in nature. We demonstrate how the course met our objectives and reflect on the opportunities and challenges it presented for our students. We highlight particular conditions that informed that success and identify areas that we will focus on in the future through a quantitative analysis of survey data and qualitative analysis of student reflections and focus groups.

2. The big picture: helping students see problems as sociotechnical

While the University of San Diego has a strong liberal arts tradition[2], we have observed that engineering students often struggle to connect what they have learned in their liberal arts courses to what they do in engineering. One explicit goal of USD's RED project is to engage faculty across campus in order to create a more interdisciplinary learning experience for engineering students. The work presented in this paper is the result of collaboration between a faculty member from Engineering (GH) and a faculty member from Peace (ACF). Having both faculties involved in the development of the course has made it possible to integrate content from two very disparate disciplines. We developed this course over a calendar year. In the semester that we offered the course, we met weekly for approximately three hours. Further, both instructors were present for all class sessions.

A second overarching goal for the USD RED project is to provide students with an engineering education that is explicitly sociotechnical in nature. This commitment is also directed by ABET outcome H, which dictates students should have "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context" [19]. This outcome emphasizes societal context as a key aspect of engineering solutions; however, the engineering curriculum often undermines this viewpoint [20]. In the engineering classroom, society is often understood narrowly in terms of the final impact that engineered technologies may have, rather than as the context in which technologies are imagined, developed, and implemented. Our goal at USD is to explicitly recognize engineering as a sociotechnical discipline. Erin Cech, a sociologist who studies inequities in STEM, argues that "prioritizing certain 'technical' features (faster, smaller, cheaper vs. quality or sustainability) over others is a social and political choice at its core. Thus, the notion that engineering work can somehow be separated from the social world is itself a cultural frame for understanding what engineering is" [21].

We developed our "Engineering Peace" course in order to help students explicitly recognize that, despite how classical engineering textbooks present problems, it is impossible to disentangle technical and social problems. While the impetus for the creation of this course came from the engineering side, faculty in peace studies similarly recognize that social problems do not exist in a vacuum but are surrounded and supported by technology. This is reflected in the Peace and Justice Studies Association's stated values, which include a commitment to the "liberatory use of technology and media research in support of community needs" [22].

The second author (Choi-Fitzpatrick) has spent the past two decades in educational and advocacy non-profit institutions. His experience is that there is a tight link between the kinds of students who enter advocacy-oriented educational programs, the kind of training they receive, and the kinds of work they go on to do. A dramatic oversimplification might suggest the advocacy world writ large (think of intergovernmental organizations like the WTO and UN, non-profits like Greenpeace and Human Rights Watch, and grassroots organizations too small and numerous to illustrate here) has traditionally focused on three key areas: *Communication*, often attracting personnel with background in psychology, media, marketing, communication, lobbying, and so forth; *Operations*, often attracting

[2] The Shiley-Marcos School of Engineering awards a dual BS/BA degree and students are required to take roughly 12 courses outside of the School, including three semesters of foreign language and two religion and theology courses.

personnel from accounting, human resources, management, and so forth; and *Techniques*, often attracting personnel with experience in health, medicine, water, infrastructure, technology, monitoring and evaluation, policymaking, the environment, and so forth. Our sense is that the advocacy world relies on various combinations of these skill sets, but that contemporary university programing is ill-equipped to prepare students for a labor market in which projects are staffed by personnel from across these backgrounds. Over the past two decades, schools focused on public service have worked to incorporate *Operations* into their curriculum. Far more work is needed to incorporate what we are here calling *Techniques*. To say something is necessary is not to say it will be easy.

We suggest a project-based course is the best pedagogical approach to help students from multiple disciplines engage with the complexity of sociotechnical problems. Project-based learning (PBL) provides a wealth of benefits to students [23–29]. Adopting a PBL approach, we built a course that allows students from very different disciplinary backgrounds to learn from each other about their disciplines as they worked collaboratively; an approach that is particularly effective for supporting student success in the ways that we outline above. This course provided opportunities for students from Schools of Peace Studies and Engineering to work together to talk about the impact and role of new technology, reflect on their disciplinary lenses, work in teams to build drones, and design a novel way of using drones to have a positive impact on society.

3. How are others approaching these challenges?

While academic communities have long bemoaned the siloization of academic disciplines, the past decade has seen increased efforts to proactively engage this issue. One point of pressure appears to be an ever-growing range of research agendas and methods that simply do not fit into traditional disciplinary boundaries. A second point of pressure appears to be the success of tech entrepreneurs who have realized market success by drawing creatively across a wide range of expertise. The fact that major innovations have come from private actors who have poached academic talent is not lost on decision-makers in the academy.

We are writing from within Schools of Engineering and Peace which are actively encouraging cross-pollination between the arts, business and finance, social justice, and engineering. There does not appear to be any single clear model for programming around interdisciplinarity, especially between the social and applied sciences. In the United States, schools focused on public service (i.e., public policy, international relations, social justice, international development and conflict resolution) rarely have joint degree programs, overlapping curriculum, or joint appointments even among schools where methods and topics of interest are closely aligned, such as those focusing on law, medicine, social work, and area studies. Rarer yet are partnerships between such schools and schools of business, environment, geography, and engineering.[3] At no point in our initial assessment of the field did we find a school of public service (as defined above) with an active link to a school of engineering.

Our research on other engineering programs indicates similar lacunae. The vast majority of today's engineering curricula have experienced few structural changes since the end of the Cold War [20]. Several groups of engineers have recognized the perils of this static curriculum and have started to make inroads in reforming engineering education. *Engineering, Social Justice, and Peace* (ESJP), is a network of activists, academics, and practitioners dedicated to infusing social justice and peace into engineering [30]. Within the American Society for Engineering Education, the *Liberal Education/Engineering & Society Division* (LEES) provides a "forum for those concerned with integrating the humanities and social sciences into engineering education via methods, courses, and curricular designs that emphasize the connectedness between the technical and non-technical dimensions of engineering learning and work [31]."

Due to the work of these groups and others, the NSF recognized the need for structural reform and launched the NSF RED program. The NSF solicitation explicitly called for structural change: "This funding opportunity enables engineering and computer science departments to lead the nation by successfully achieving significant sustainable changes necessary to overcome longstanding issues in their undergraduate programs and educate inclusive communities of engineering and computer science students prepared to solve 21st-century challenges [32]." Indeed, there are few other engineering programs across the country that focus on providing students with a sociotechnical engineering education. Notable exceptions are Humanitarian Engineering programs at Colorado School of Mines [33] and Oregon State University [34] aimed at training engineers to provide socially responsible solutions (though this is not an exhaustive list). In 2018 Drexel started an MS program in Peace

[3] Attentive readers will note that this is starting to change, though an informal assessment of public policy programs by the second author suggests this process is slower than many Deans might prefer.

Engineering, making it "the nation's first program dedicated to preventing and reducing violent conflict through education and research that integrates innovative technologies, approaches, and policies with the studies and practices of peacebuilders [35]."

Further, while other courses on drones exist, our interdisciplinary approach is unique. It differs significantly from the two primary approaches to teaching about drones that other programs use: engineering practice or social science theory. Several universities in the United States offer classes on the construction, repair, and flight of UAVs [36]. Kansas State Polytechnic has one of the first and only bachelor's degrees in UAS systems [37]. The degree combines general education requirements and the coursework for a degree in aircraft piloting with a series of classes on electronics, control systems, and drone systems in particular. Similar degrees are on offer at other universities including Oklahoma State University [38] and the University of North Dakota [39]. While these classes focus on the construction and control of drones, they do not train students to evaluate the sociotechnical challenges of this technology.

Closer in nature to our project is the Center for the Study of the Drone at Bard, where Center cofounder Arthur Holland Michel developed and taught a 2016 class called "The Drone Revolutions" in Bard's Human Rights Program [40]. This class pioneered a critical approach to the important uses and users, as well as emerging issues around technical innovation, culture, politics, and ethics. Michel's class focuses on key themes that drone-specific programs appear to leave to the side. However, the course does not appear to give students a hands-on experience with the technology.

While the topic is unique, familiarizing students with drone technology and theory is not our goal. Rather, we developed this course to bridge the gap between theory and practice in engineering as well as peace studies. This effort is rooted in a commitment to equipping thoughtful engineers and practically-minded social scientists and humanists. We chose to focus on drones specifically for three reasons: (1) they are of topical interest to the students; (2) they present an ideal combination of technical and ethical challenges that require students from different disciplinary backgrounds to wrestle together with unfamiliar questions; and (3) recent technology advances and open source software have dramatically reduced the price such that components for a complete drone can be purchased for less than $100.

This class could just as easily been based on the emergence of citizen science around environmental issues, and explored the sorts of applied engineering problems faced by grassroots activists using the basic scientific tools provided by efforts like Citizen Lab, a non-profit that allows everyday people to do what the sociologist David Hess has called *undone science* [41]. Our class could have easily collaborated instead with Project Concern International, a San Diego-based international aid organization using satellite imagery to help pastoralists in Africa find pastures for grazing. In sum, our class on drones is technology agnostic, and our commitment to bridging the applied and social sciences is, we hope, motivational to others.

Bridging different disciplines involves incorporating different epistemological orientations to project-based learning into the classroom, making teamwork incredibly rich, as well as deeply challenging, for participants [42–44]. Teamwork across disciplines can be either *multi*disciplinarity or *inter*disciplinarity. The two concepts have a great deal common, but may entail slightly different outcomes for participants and for their projects.

Briefly, in *multi*disciplinary work, collaborators work together on a problem. Each brings expertise, but, as Borrego and Newswander explain in their overview of cross-disciplinary engineering collaboration, "collaborators leave the project without having learned much about the other discipline(s). Each researcher continues on his or her own independent trajectory, unchanged by the experience" [45]. This means that although multidisciplinary work brings together people with different ways of conceptualizing and operating on problems, each takes on their specialized tasks without necessarily exchanging a great deal of information about those responsibilities in the process. Researchers understand multidisciplinary collaborators to maintain their own disciplinary lenses and commitments, and make a distinction between multidisciplinary collaboration and interdisciplinary collaboration in this respect [46, 47].

In contrast, *inter*disciplinary work moves beyond a division of labor to instead engage in more thorough collaboration and sharing of knowledge. "At the end of a truly interdisciplinary collaboration, each collaborator is changed by the experience," Borrego and Newswander summarize [45]. Facilitating this kind of transformative experience as well as the development of all-important project management and teamwork skills for students can be deeply attractive for educators focused on preparing students for a successful professional life. Interdisciplinarity is demanding and can be difficult to create in the classroom. The term "interdisciplinary" may be used to refer to a process (for example, a multidisciplinary teamwork practice that involves discussion and collaborative problem-solving), an outcome (a solution to a problem that incorporates insights from different disciplines), or even an effect for participants (a transformation in participants' perspective after collaborative work with colleagues from other disciplines). With Engineering Peace, we developed a framework for challenging, productive interdisciplinary collaboration in the context of a project-based course.

4. Our project-based course

We sought to address the gap between theoretical calls for interdisciplinary work and practice in the classroom through the creation of a unique, project-based course framed around the open source technology of drones. A broad goal of the course was to task engineering students and peace studies students with a project that was sociotechnical. Following recommendations from WPI's Center for Project-based Learning [48], we designed our course to give students a set of authentic experiences that would help them to see the value of interdisciplinary work. Our approach to PBL uses structures and rules, like lab safety trainings, to support student skill development and safety. It also provides time for students to experiment with those skills, using trial and error to really engage with the project at hand.

We intentionally matched our course deliverables with the University's well-resourced and heavily-promoted Social Innovation Challenge (SIC), a pitch competition for ideas that enhance the greater good. In so doing we hoped teams would have an incentive to work harder on a class project for which they could imagine a longer trajectory. It also allowed us to import some of the SIC's selective incentives to our class—doing well on an in-class project increased the likelihood that they secured a higher grade in our class, but also that they secured funding and support at a later date via the SIC.

As indicated earlier, this project was made possible through RED resources secured by the School of Engineering. We teach at a University committed to the liberal arts tradition, with an emphasis on conscientious service (USD is an "engaged contemporary Catholic university" and an Ashoka Changemaker Campus). Departmentally, both of our Deans supported this effort and allowed us to co-teach with full FTE credit going to each of us. Personally, we each have interest and experience in sociotechnical systems generally, and drones in particular. We do not know whether these are necessary or sufficient conditions for such a course, but do believe this particular confluence is important to emphasize.

4.1 Learning objectives

Our learning objectives focused on students' abilities in relationship to broader contextual issues (process), the technical challenge and its social implications (project), and their role in the process (reflection). These were operationalized in the syllabus as follows. *Process*: describe the "lens" of one's disciplinary framework; find, read, and incorporate information from across multiple disciplines; and communicate one's perspective and decision-making process to colleagues from other disciplines. *Project*: design and build a drone using open source technology; create a proof of concept for use of this technology that has a positive social impact; plan and implement projects in an interdisciplinary team environment; and collaborate with others to describe this concept in a compelling way. *Reflection*: articulate in verbal and written form the role of interdisciplinary teams; identify the strengths of others when working on team projects; and leverage a sense of empathy to see things from a different perspective.

4.2 Course design

We operationalized these learning objectives through specific course components by dividing the course roughly into thirds. We spent the first phase of the course in a combination of mini-lectures and class or group discussion of key concepts related to disciplinarity, technology, and social change. At the conclusion of this phase we assigned the students into teams and moved into two project-based modules. In the second phase of the course we had students build an open-source drone from parts we provided. In the third phase of the course we had students discuss, develop, and prototype a use for a drone that has a positive social impact as well as prepare the final project pitch they would develop at the semester's end. (For those readers interested in implementing our mini-lectures, facilitating similar discussions, or building drones in their own classes, please send us an email. We would be happy to provide detailed lesson plans and information about what components to order.)

4.2.1 Phase one: exploring technology and social change

This set of class meetings allowed students to gain familiarity with the basic assumptions, weaknesses, and strengths of the disciplinarity represented in the class. It also gave them a chance to get to know each other before being thrust into a team project. As a part of this early third of the course, we asked students to individually record short video pitches for how they wanted to use a drone to have a positive impact on society. This was the first of several brainstorming exercises we used to help generate a rich diversity of ideas among the students on how drones might be used to have a positive impact on society.

From these early brainstorming activities a few themes emerged that later evolved into the students final projects. In the third week of the course we sent out a survey to the students with the topics they had identified and asked them to rank them in order of preference. Using this information, as well as student demographics, we formed teams of four. We should note that while interest was an important driver in our team formation, it was not the only factor. The literature on team formation indicates that students have the best outcomes when women and minorities are not isolated on a team (i.e., it is better to create one team with two women and one team with all men rather than to split the women up, one on each team) [49]. Forming teams in this way helps ensure all student voices are recognized, rather than marginalized, on the team. We thought that we might see similar problems if we isolated students from a particular major on a team, so we aimed to create teams with two engineers and two peace studies students. We formed teams that were a good balance of interest, gender, race, and major. We did not tell the students what their shared interests were when we assigned the teams. Upon announcing the teams we simply allowed the students to continue their brainstorming and select a project that would work for all of them.

4.2.2 Phase 2: building an open-source drone

In the second phase of the course, students worked together in their teams to build a small drone platform known as a quadcopter, see Fig. 1. The objective here was to move interdisciplinary student teams through a build phase in such a way that engineers experienced some modest technical challenges, but were able to assist peace studies students who experienced hurdles. Relating to the theme of the class, we wanted students to see the contrast between the relative ease with which quadcopters can be built and the complexity of the engineering that has gone on behind the scenes in making this platform widely available.

From a pedagogical perspective, quadcopters offer several advantages. First—due in large part to Chinese manufacturers that sell inexpensive components on sites like HobbyKing.com and Banggood.com—for about $200 it is possible to procure all of the components for a high performance drone. In fact, for the second offering of the course, we made a slightly smaller indoor version of the drone that cost less than $80. This meant that for the price of a traditional textbook, faculty can send each student home with their own drone. Second, the quadcopter invites interesting discussion on open-source development for software. There are over ten major open-source platforms used for quadcopters, each with an interesting history of development.[4] In our class we have used Librepilot and Beta-flight, two of the most popular open-source packages. (For a detailed list of components and prices please send us an email.)

Fig. 1. The drone that students built in the second phase of the class.

In this stage of the course very little reading was assigned other than a handful of technical documents needed to support the build process. On the first day of the build we provided the students with a bucket filled with components and challenged them to unpack all of the components and determine their overall function. We encouraged them to go online and look up the components, making them the stewards of their own learning. That exercise concluded with an oral presentation in which one of the peace students from the team had to explain to an instructor how they would eventually assemble the components. For the subsequent build sessions we provided students with some basic instructions to ensure they hurt neither themselves nor the hardware. As the build was ongoing, we reminded the engineering students that their job was to serve primarily as facilitators—helping their peace studies colleagues to get some hands-on experience assembling technology. We were pleased to see that contrary to our expectations, little policing was needed on our part to make sure the engineering students did not simply take over the build process. While we originally budgeted only two weeks of class for the build, in the end it took roughly four weeks from start to finish. We were quite happy to see the build take this long—as we will discuss in the

[4] The current popularity of quadcopters can be traced back to the release of the Nintendo Wii. The Wii controller was one of the first mainstream commercial products to contain the MEMS based accelerometers and gyroscopes that are now ubiquitous in smart phones. These are the key components in the brain of the quadcopter—they are what makes flight possible. Avid quadcopter enthusiasts disassembled many a Wii controller to scavenge them for parts. Armed with these powerful sensors, the last decade has seen an explosion of open-source flight control software for drones. One of the early software platforms was dubbed MultiWii—an homage to the Nintendo Wii from which the sensors came [60].

results, this was a valuable time for students to engage in cross disciplinary collaboration.

4.2.3 Phase 3: designing a drone with a positive social impact

The third and final stage of the course was spent discussing, developing, and prototyping a drone that could have a positive impact on society. This phase of the class focused on the early stages of the engineering process—problem identification, ideation, and prototyping. Unlike many traditional engineering design courses, however, the final product for our class was explicitly *not* a piece of hardware. Instead we challenged the students to prepare a compelling pitch for why someone should fund their idea. The engineering work they did to define the project was always done in consideration of how they would use that work to convince an outside investor to fund their idea. We drew heavily on resources from the Lean Startup methodology [50] and the KEEN Entrepreneurial Network [51].

One key assignment for students in this phase was the development of a minimum viable product (MVP), a concept defined by Lean Startup founder Eric Ries as "that version of a new product which allows a team to collect the maximum amount of validated learning about customers with the least effort [52]." An MVP is explicitly *not* a prototype of the full system, but instead is something that allows designers to conduct some kind of test about the assumptions baked into their product. For example, when one of our teams proposed using a drone as a tool to examine palm trees for weevil infestations (a problem local to San Diego), they started off imagining they needed to build a full drone system with a camera to test their idea. After a few conversations with the team, we helped the students realize their fundamental question was not whether a drone could fly over palm trees (which it obviously can), but how close the camera needs to be to the tree to detect a palm weevil infestation. Recognizing this as the critical assumption in need of testing, the students realized their MVP could be as simple as attaching a digital camera to a long pole in order to take photos of a palm tree from several distances (see Fig. 2).

Fig. 2. The minimum viable product developed by a team designing a drone to inspect palm trees for palm weevil infestations.

The final deliverable for the class was a 6-minute entrepreneurial pitch designed to convince the relevant stakeholders (as determined by the project topic) to adopt the team's idea for a drone that has a positive social impact. We intentionally kept the presentation short, forcing students to craft a clear and cohesive message. Rather than simply having the students present to us, we invited three external judges to evaluate the students: a drone enthusiast who was also the chair of the University's Anthropology Department; a retired US Navy drone pilot; and the Assistant Director for the University's Center for Peace and Commerce. The public nature of the presentation substantially increased the immediacy of the experience for students and substantially changed student attitudes towards the presentations. We supported student development of this presentation using the Elevator Pitch online module developed under a KEEN grant by the University of New Haven [53]. While our students reported that the online delivery of the material was frustrating, they thought that the content was quite valuable. We found the entrepreneurial pitch to be a valuable pedagogical tool in motivating student's engineering design work and frequently referred to it during our meetings with the teams.

5. Methods of data collection and analysis

This article draws on the analysis of qualitative and quantitative data produced by the study's multi methods research approach. Qualitative methods include thematic analysis of student work; focus group discussions; faculty reflections; and ethnographic observations of the class. Quantitative methods include analysis of student surveys (pre/post) and student work. All instruments and processes described here were vetted by USD's Institutional Review Board (IRB) to ensure an ethical research process. Our class was attended by 24 students, 14 of these were engineers (3 women and 11 men) and 10 were peace studies students (8 women and 2 men). This serves as the baseline population size for the discussion that follows of our mixed-method approach.

5.1 Qualitative methods

Student work—We report here on thematic analysis of the mid-term essay and a final reflection essay. These essays prompted students to reflect on the process, their role in the process, and their experience of teamwork. Question prompts were open-ended in order to invite a wide range of responses. Dr. Reddy analyzed and coded these data for themes related to collaboration across.

Focus Group Discussions—In the final days of the class, each team participated in a focus group discussion. These focus groups lasted between 15-30 minutes. They were shown a short video of themselves, working together on the drone project. Then they were asked to respond to a series of prompts to encourage them to discuss their experience working together, course themes and what they felt that they learned, and the course's implications for their own future. These data were analyzed by Dr. Reddy, who coded for themes related to learning objectives, broader objectives of the course, and emergent conditions of possibility for the course's success.

Faculty Reflections—Drs. Hoople and Choi-Fitzpatrick wrote reflections on the class progress regularly throughout the course. These data were analyzed by Dr. Reddy, who coded them for themes related to course challenges.

Classroom Observations—All teams were observed throughout the semester by Drs. Hoople and Choi-Fitzpatrick. While Drs. Hoople and Choi-Fitzpatrick, the instructors of record, were present every day, Dr. Reddy attended six class sessions during which students went to work on assembling and designing drones.

Anonymous Student Evaluations—We collected qualitative anonymous student evaluation data. Student responses were only identified as "engineer" or "peace studies." Students were asked to respond to three questions: (1) Do you find this class to be intellectually challenging? Why or Why not? (2) What aspects of this class contributed most to your learning? (3) What aspects of this class detracted from your learning?

5.2 Quantitative methods

Pre- and post-surveys—In a survey of students before and after their class experience, each was asked a number of questions related to teamwork. These questions were asked again in a post-survey, along with several further questions asking students to reflect on the impact that this class had for them and to identify particularly useful aspects of the course. To compare the pre- and post- results we used the non-parametric Wilcoxon Rank Sum Test (Mann Whitney U Test) as our data sets are small, non-continuous, and not normally distributed. All calculations were performed using the software package R.

Our analysis of this longitudinal data suggests that student self-assessments changed between the pre- and post-surveys. Students understood the course to have had a strong positive affect on their abilities and comfort with team projects, which we found encouraging but not very interesting. We anticipated that students would report confidence upon starting the course, only to later discover that interdisciplinary work is considerably harder than they realized. While this hypothesis might be accurate, it is hard to test quantitatively. Some of these high self-assessments may be an example of a Dunning–Kruger Effect, in which, as Dunning explains, "poor performers . . . seem largely unaware of just how deficient their expertise is" [54].

Student work—Student reflections on their team experiences were coded for empathetic statements and analyzed by Dr. Reddy.

Anonymous End of Semester Survey—We also collected quantitative anonymous student evaluation data. Again, each data point was only identified only as engineer or peace studies. We used the University of Washington IASystem Form K, a validated instrument for measuring faculty performance [55].

6. Findings

> "This class made me think very creatively about problems facing the world today, and how interdisciplinary teams can be useful in solving those problems."—Anonymous Student Comment.

To students we framed our class as an experiment—a chance to try out a new pedagogical approach to interdisciplinary education. We were unsure how students would react, as courses integrating engineering and issues of peace and justice are often met with student resistance. Our students, however, proved receptive. In the anonymous end-of-semester quantitative survey, engineering students ($n = 15$) rated "The course as a whole" 4.7 out of 5 (between Excellent and Very Good). The peace studies students ($n = 8$) also had a positive experience, reporting on the same measure 3.8/5 (between Good and Very Good) (Note that while these mean values are different, the difference between these two means is not statistically significant: Wilcoxon Rank Sum Test, unpaired, two-sided, $W = 85$, $p = 0.09$). There is no doubt that the course was unique. When asked to reflect on what they learned in the class in focus groups, students in most teams (5/6) noted that this course was unlike others in their experiences. Although students had distribution requirements as part of the University's Liberal Arts educational mission, this kind of work was different. As one engineering student put it, although he had done projects in other classes, "I think it matters a lot based on when I'm with someone else in another class, we're all still working on that class. We're not working on a cross-discipline project, like the actual projects you do are still single disciplined."

This course offered a different kind of learning opportunity. Engineering students in 2/6 teams reflected that, while they were often told about the value and necessity of partnerships across disciplines, they rarely got the chance to do it. One said that "I think in like our mechanical engineering classes we always talk, like, 'Oh, you're never going be on a team with just MEs, like that's never going to happen.' But then, in everything we do we're on a team with just MEs. And so it's like, okay, well like what's this experience actually going to be like?"

Peace studies students made similar observations. In their other classes, they dealt with critique and theory, but did not often put these into practice. One peace studies student commented that "This class was meaningful for me because at least we moved from analyzing to doing something in reality and that helped a lot. It's given me. . . hope to [do] a lot of things."

6.1 Did we meet our learning objectives?

While it is always nice to offer a class that students enjoy, far more important is what students actually learn. We broke our learning objectives up into three groups: process, project, and reflection. Assessing student learning in project-based learning can often be tricky, but as we will describe below we carefully structured our assignments so that they clearly lined up with our learning outcomes. We argue that, by and large, we successfully met our learning objectives.

6.1.1 Process learning objectives

Our process learning objectives focused on getting students to recognize their own discipline and communicate across disciplines. We primarily focused on these issues for the first third of the class and assessed student learning through a midterm essay, self-reported gains on a pre/post survey, and a final presentation. In the midterm essay we asked students to "clearly articulate the disciplinary lens that you have developed as a student at USD" followed by a prompt that required them to synthesize information from across multiple disciplines into a coherent argument. After coding the student responses, we were pleased that to see that all but one student had scored a 4 or 5 on each of the prompts.

Students' self-reported survey data also confirmed that they had improved their ability in describing their disciplinary framework and synthesize across disciplines. In our pre/post survey we asked students a 5 point Likert scale question "How capable do you feel in describing the disciplinary lens/perspective of your degree (major or masters)? (1—Very Incapable to 5—Very Capable)." Student responses moved from an average of 4.3 to 4.7 over the course of the semester, a statistically significant increase (Wilcoxon Rank Sum Test, one-sided, paired, $V = 0$, p-value = 0.002). We also asked "How comfortable do you feel about your ability to synthesize information from across multiple disciplines? (1—Very Uncomfortable to 5—Very Comfortable)." Student responses began the semester at 4.2 and ended at 4.5, again a statistically significant result (Wilcoxon Rank Sum Test, one-sided, paired, $V = 4.5$, p-value = 0.02).

Another key process outcome was that we wanted

Table 1. Summary of findings

Research Question	Assessment Method	Findings
Were students receptive to this style of instruction?	Anonymous Student Evaluations, Focus Group	Yes. Both groups of students found the course rewarding. The opportunity for interdisciplinary teams was highly valued.
Did students achieve the process learning outcomes?	Student Work, Focus Group, Faculty Reflections, Classroom Observation, Pre/Post survey	Yes. Students both improved on their ability to work across disciplines and reported feeling more confident about these abilities after taking the course.
Did students achieve the project learning outcomes?	Student Work, Focus Group, Faculty Reflections, Classroom Observation, Pre/Post survey	Yes, students successfully completed the build of a small quadcopter platform. They also designed a pro-social drone and delivered a compelling pitch to a group of external judges.
Did students achieve the reflection learning outcomes?	Focus Group, Faculty Reflections, Classroom Observation, Pre/Post survey	Maybe. It seems likely the course had a positive impact on students in this area, but this factor was the hardest to measure. Students engaged in multiple reflection exercises and demonstrated empathic behavior towards their peers. They reported that interdisciplinary teams are more effective than homogenous teams.

our students to be comfortable communicating their decision-making process to colleagues from other disciplines. We assessed this outcome by evaluating student performance on the final pitch at the end of the semester. As the judges met to select the winner of the pitch competition, the panel was impressed with the students' performance and had difficulty in selecting the winner. In particular we noted that the students had gone out of their way to communicate across disciplines – the engineers did not just present technical information geared towards the other engineers in the room. As instructors we were pleased to see that regardless of disciplinary background, then panel had understood each of the teams concepts. Given the both favorable reviews by the external judges and students own positive reflections, we feel we achieved this learning outcome.[5]

6.1.2 Project learning objectives

All student teams successfully completed the class project and the associated learning objectives. We had students begin working in their teams on the collaborative experience of building small prototype drone platforms. We challenged the engineers to be as hands-off as possible during the build, instead serving as mentors to the peace students, who had considerably less hands on experience. Concurrently with the build, teams of students spent roughly six weeks developing and refining their use for a drone. We encouraged them to dream big, as they were not required to match the proposed use case to the diminutive size of the platform we were building in class. Likewise, we did not place any constraints on the challenge such that the project would require attaching something to a drone. Viable approaches could envision new ways of managing existing technology, for example. While several teams adopted off-the-shelf technology and others built CAD designs of and 3D printed samples of unique platforms, all envisioned drone-centric approaches to their projects.

One case study is perhaps illustrative of the general trends and trajectories across teams. The team identified fires in refugee camps as the problem that would animate their project. One of the team-members served in an official capacity for a national government and had in his portfolio the oversight of refugee camps. In these camps, cook fires in make-shift structures often led to fires. These fires spread quickly due to crowded camp layout, were difficult to identify because of hilly terrain, and were difficult to mobilize responses to because of weak camp-wide communication facilities. The team's solution was to equip a proven off-the-shelf drone platform with the capacity to both loiter while identifying the location of a fire and to help fire-fighting members of the community to quickly locate the fire by sounding an alarm. Several weeks were spent identifying the exact nature of the broader context. Here it was imperative that the team was comprised of several key actors. First, it proved important that the team's understanding of the problem was informed by a stakeholder from the affected community. Second, it was crucial that the team included someone with the technical proficiency to operationalize the vision and design the prototype. Finally, it was critical that the specifics of the problem and solution were complemented by a broader perspective on the social and cultural factors at play in implementing this solution. Each team had a different trajectory, but they all learned to plan and implement projects in an interdisciplinary team environment while collaborating with others to describe their concepts in a compelling way

6.1.3 Reflection

A major component for our class was an opportunity for students to reflect on the experience of working in an interdisciplinary team. After the class, students were asked "In your opinion, are interdisciplinary teams more effective than teams made up of members from a single discipline?" On a 5 point Likert scale students agreed strongly with an average response of 4.4—that is, between Much More Effective and Somewhat More Effective. We hoped to help students develop empathy for each other. By *empathy* we mean a "feeling a congruent emotion with another person, in virtue of perceiving her emotion with some mental process such as imitation, simulation, projection, or imagination" [56]. This approach, which we borrow from Oxley's *The Moral Dimensions of Empathy* [56] and emphasize elsewhere [1], suggests empathy works in two

[5] We also investigated this outcome using a series of survey questions. We asked students at the start of the semester a 5 point Likert scale question: "How comfortable do you feel about your ability to communicate with colleagues from other disciplines? (1—Very Uncomfortable to 5—Very Comfortable)." Students were very positive about their own abilities, 15 of 20 students chose "5—Very Comfortable." Interestingly in the post survey, even with all of the practice they received working in interdisciplinary teams, three of those students actually revised their answer down to "4-somewhat comfortable." We believe the responses to this question are likely an example of the Dunning–Kruger Effect [54]. We suspected that students, having had little practice working on interdisciplinary team projects, would be overconfident in their ability to communicate across disciplinary boundaries. Anticipating this result we also asked students on the post survey "What kind of impact has your experience in this course had on the comfort you feel with colleagues from other areas of study? (1—Decreased Comfort significantly to 5—Increased Comfort Significantly)." Here the students reported a positive impact from the class—the class average was 4.3, between "Somewhat Increased Comfort" and "Increased Comfort Significantly."

ways. It has an affective dimension, in which emotions are transferred between people, and it has a cognitive dimension, in which one can better understand how another sees the world. Empathy has an emotive as well as cognitive dimension.

Operationalizing "empathy" is notoriously difficult, something flagged by critics [57] and supporters [58, 59] alike. In this study we have done so by way of an assessment of each student's final reflections on their teammates. First, these reflections were coded qualitatively for explicit statements about the particular feelings, emotional states, or lifeworlds of one of their teammates. Then they were quantitatively analyzed. By this measure, each student had three teammates and thus three opportunities to make empathetic statements. Eight out of the 14 engineering students who participated made at least 2 empathetic statements about at least two people in this final reflection, and 6 of them (that is, 43%) made empathetic statements about all of their teammates. Similarly, 5 of the 10 peace studies students who participated made 2 empathetic statements about at least two people, and 2 of them (20%) made these statements about all of their teammates. As this is a new measure we have created we have nothing to compare it against, but we plan in future work to use this measure to assess empathy in multiple settings. Our intuition as instructors suggests students in this class demonstrated more empathic behavior than in other classes we have taught.

6.2 Did we meet our broader objectives?

Explicit goals of the RED project include (1) engaging faculty across campus in order to create interdisciplinary learning experiences for engineering students, (2) providing students with an engineering education that is explicitly sociotechnical in nature, and (3) developing a revitalized engineering educational culture.

These goals require rethinking engineering itself to include interdisciplinary and sociotechnical projects. However, when we asked students in focus groups what they thought this class was about, students did not think it was about engineering. It did not seem like an engineering class. Nor, for that matter, did they consider it to be a peace class. In two focus groups in particular, students took time to discuss their perspectives on this topic. One engineer reflected that "The design aspect just was not very engineering . . . it was more of like a hard Lego kit to put together." While a colleague disagreed with him, pointing out that there were plenty of engineering positions in which design did not mean building everything from scratch, the opinion that the course was not precisely engineering because of the limited design and calculation was widely held. It was very "plug and play," requiring that teams follow instruction rather than analyze power or structures or design or modify parts.

We agree with this characterization for the drone build: we provided components for the students and they had to figure out how to put them together. However, beyond this superficial agreement there is an interesting gap between our own assessment (that we focused too much on engineering-related issues) and the perception of engineering students (that this was not *real* engineering, i.e., exclusively and explicitly technological).

We spent nearly half the class on the engineering topics of problem definition, ideation, and prototyping. These are critical skills for engineers, but they make up a proportionately small part of standard engineering curricula. As Leydens and Lucena discuss in their work [20], the current emphasis on engineering sciences within most degree programs trains students to think of engineering only as solving narrow technical problems, often the kind that are accompanied by answers in the back of a textbook. In future offerings, we will be more explicit about this dichotomy. Hopefully by inviting students to critically reflect on their own education, we can help them broaden their own working definition of what counts as engineering. Our interactions with peace studies students left us with the sense that they felt sufficiently challenged, and had indeed experienced and engaged engineering on its own terms.

6.3 Key takeaways from the course and next steps

Interdisciplinary project-based coursework has advantages that were apparent to students. In four of the six focus groups, students described working in these teams as a great benefit to their projects. They described how early brainstorming, critique, and practical project planning benefitted from heterogeneous team composition.

For peace students, the technical work set the class apart from others they had experienced. In a focus group, one commented that she may have learned about peace and justice but reflected that ". . . this is not how we do it over there." It was not just a matter of working in an engineering space that set the course apart, however. With engineers, peace students could experiment with new ways of approaching problems where, as one put it, they could learn about "pitching an idea that's, like, not just a positive social impact, but, like, practical . . . doable."

Engineering students found that working with peace students had benefits, too. One engineer suggested that: ". . . when you talk to an engineer you get one perspective, and because of the way we've been trained that's usually the same. But when we talk to a peace and justice student, I'm like, 'Oh, I never thought about all these other possibilities.' "

While the experience of the course was rewarding to both sets of students, their differences made for some real challenges. We found that scheduling meetings was incredibly challenging, with serious implications for the course. Engineers were undergraduates who tended to have most of their classes early in the morning, while peace students were graduate students who tended to have class at night. This made it hard to find time for groupwork outside of class. We also found that engineering students seemed to be getting more out of the course than the students from peace, possibly because we dedicated more class time to deconstructing engineering than on exploring the implications of applied projects on peace and justice work.

In future semesters we plan to make two changes. First, we will have smaller groups build drones that they can each keep after the class is finished. Second we will discuss non-profit and advocacy work more often and more explicitly. We suspect that variations in student engagement may also have been due to a self-selection bias. The engineering students all sought out the course. In fact, there was more demand than we could accommodate. For the Peace students, a scheduling conflict meant that some of the students most excited in the course could not enroll, while others enrolled because it was the only course that fit their schedule.

7. Conclusion

The ultimate goal of our RED project is to develop a revitalized engineering educational culture. Our course focused on helping students to think about how to have a positive impact on society. To this end, we argue that engineers must recognize sustainability as a core tenet of the engineering process.[6] Similarly, we argue that all engineers should recognize their role as humanitarians—i.e. they are responsible for designing solutions that promote human welfare—with a rich understanding of how contexts impact these solutions. When students truly begin to understand the role of social justice in engineering, they see that apparently humanitarian solutions—such as promising jobs to indigenous communities in exchange for mining rights—often turn out to have lasting negative consequences. To better explore these complex tradeoffs, we challenged students to come up with ideas for how to use a drone to have a positive impact on society. As they soon discovered, this is no simple task.

In this article we have provided a conceptual and empirical overview of a class-based experiment in combining students from a Schools of Engineering and of Peace Studies into a class that draws across the strengths in both fields. Our interest in this effort is personal, professional, and institutional but we feel our findings have implications for engineering education as well. In particular, we believe that we have piloted a replicable model for engaging students from multiple schools and backgrounds around a particular sociotechnical puzzle, its attendant social and technical challenges, and associated ramifications. While we tested our model using drone technology, we could just as easily have run the class with students from Engineering and Medicine focused on a medical device or from Engineering and Environmental Science focused on citizen science. Run the other way, this course could just as easily have been a collaboration between the School of Peace and a School of Architecture on refugee camps or with students from both Peace and Cryptography on privacy.

This effort has been resource-intensive in terms of both human capital (we spent one year developing this course, have relied on the excellent support of two TAs, one post-doc, and have two faculty in the classroom at all times) and financial capital (we have drawn on summer research funds, material costs for equipment, and so forth). While much of this work has been conducted under the auspices of funding from the National Science Foundation, further refinements will be necessary before this class can operate according to the usual laws of institutional gravity. That said, the use of open source technologies around drones provides a path forward—the cost for these components and lack of software licenses makes it possible to sustain this class with a lab fee that costs less than a textbook.

In the final analysis, however, we hope this study contributes to important ongoing conversations relating to engineering education as well as solutions-oriented social science. Furthermore, it demonstrates the potential for administrators, individual units, and individual faculty to work together on a joint inter-disciplinary classroom engagement.

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[6] Here we follow the sustainable development goals approach and define sustainability along the lines established in the seminal United Nations Brundtland Report, as "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs [61]."

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