Creative Curricula for Changemaking Engineers

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***Abstract*—A curriculum has been designed to help students become Changemaking Engineers with a sense of social responsibility and social justice. Courses include: (1) a User-Centered Design (UCD) course for first year students, (2) a Circuits course for second year students, (3) an Engineering and Social Justice course for third year students, and (4) an upper division elective on Engineering Peace. Students in UCD learn methods for engineering innovation that meet the needs of users in the local community. In Circuits, students explore how electrical circuits are related to conflict minerals, recycling, and design considerations for responsible social innovation. In Engineering and Social Justice, students consider historical and contemporary contexts to analyze impacts of engineering designs, systems, processes, and products. In Engineering Peace, students from the School of Engineering and the School of Peace Studies come together to design a drone with a positive impact on society and recognize the value of perspectives from other disciplines. This paper details the methods and highlights the successes and challenges experienced as these different but coordinated course offerings were developed.**

Keywords—curriculum; innovation; social responsibility; sociotechnical

I. INTRODUCTION

Leaders in engineering education have called for educators to move beyond a narrow focus on the technical to educate students about "context" [1-6]. By "context," the authors mean a variety of concepts and skills that may not be traditionally taught in engineering. The authors seek to design education around what Dean Nieusma has described as an expansive vision of engineering in society [1]. It is understood that these concepts and skills to be critical for students' long-term professional success and wellbeing. Leaders in engineering education are identifying social justice and peace as helpful ways to approach context in the classroom and talk about its importance [2, 3, 4, 5, 6]. Focusing on these issues can help educators think about how to address context and achieve ABET outcomes related to social and global impact [7] that are typically challenging for engineering instructors who are focused on teaching a large amount of technical content.

At the University of San Diego (USD), the authors are working on "Developing Changemaking Engineers" to prepare students to innovate engineering solutions within a contextual framework that embeds humanitarian, peace, sustainability, and social justice approaches in students' technical engineering education. This requires an enhanced curriculum with a focus on student teamwork, a greater consideration of social context, improved communication with diverse constituents, and reflection on an ethical understanding of their decisions and solutions. Effective faculty members need to mirror these values and skills in their instruction and mentoring. Efforts have begun to reimagine the "engineering canon" which requires a shift from positioning engineering as a purely technical endeavor to framing it as sociotechnical [8].

As part of this endeavor, curricula at all levels of the undergraduate engineering experience are being developed. Some of these courses are revised (*User-Centered Design*) and some are new (*Engineering and Social Justice* and *Engineering Peace*) [9-12]. In other courses, modules related to these themes are incorporated (*Electrical Circuits*, *Engineering Materials Science* [13, 14], and *Heat Transfer* [15], the latter two of which will not be described for this publication). In this paper, methods will be described and the experienced successes and challenges will be highlighted. It is the hope for this paper to be helpful to other engineering educators interested in integrating more context into their curricula and promoting peace engineering.

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II. COURSES

The USD Shiley-Marcos School of Engineering offers majors in Electrical (EE), General (GE), Industrial and Systems (ISE), and Mechanical (ME) engineering. All engineering students follow the same curriculum for the first three semesters. Courses in the curriculum that are designed to help students become Changemaking Engineers are summarized in Table 1 and described in more detail below.

TABLE I. CHANGEMAKING ENGINEERING COURSES

Year of Student	Course Title	Required (R) or Elective (E)?	Modules (M) or Through out (T)?
First or Second	User-Centered Design (ENGR 103)	R for all engineers	T
Second	Electrical Circuits (ELEC 201)	R for EE, GE, and ME; E for ISE	M
Third	Engineering and Social Justice (GENG 350)	R for GE; E for others	T
Third, Fourth, or Fifth	Engineering Peace (GENG 494)	E for all	T

A. User-Centered Design (UCD)

UCD is a required class for all engineering majors taken in the second or third semester. Multiple sections are offered each semester. This version has been offered since Spring 2017 with about 40 students in the Fall and 90 in the Spring.

UCD introduces students to strategies for identifying the needs, capabilities, and behaviors of a user group and developing designs that reflect empathy gained for the user group to address their needs. It includes iterative design methods to elicit user requirements, generate alternative designs, develop low-fidelity prototypes, and evaluate designs from the perspective of the users. For the culminating course project, students develop relationships with users in the local community and design an engineering innovation that meets their needs. Current iterations of the course involve pairing students with community organizations that provide services for people with disabilities in an effort by the instructors to approach topics of social justice and privilege through, first, an ableism lens.

As a lower division engineering course, *UCD* introduces students to the idea that engineering is not just a technical field but rather a sociotechnical and sociopolitical endeavor. Using the context of disability studies, students confront the reality that engineering technologies are not objective – rather they are designed by people and designed to impact people. In an activity where students explore controversial engineering technologies (e.g., sign language gloves [16]), they are required to reflect on questions such as: What is the nature of the controversy around the innovation? What are the lasting positive and negative implications/ impacts/ consequences of the innovation? Who is the technology designed for? Who are the designers/ decision makers? and Who does the technology provide a dis/advantage for? This activity, among others, is used to help students learn to think critically about design in general, and in turn, to apply this critical lens when working on their own design projects. By the time the students get to the culminating project, the expectation is that their design decisions will be influenced by empathy developed for the users, rather than assumptions based on stereotypes.

A version of the privilege walk [17] is also explored in this course to help students reflect on their own privilege and positionality. Discussions of privilege can be challenging or uncomfortable for both engineering students to face and engineering instructors to lead. However, dialogue about the role of engineers within the engineering discipline (i.e., inward facing) as well as the discipline's cumulative impact on society (i.e., outward facing) is important to address in social justice conversations.

Since this course is offered in the first two years of the curriculum, the maturity level of the students plays a large role in each course section's outcomes. While the course still faces some challenges being accepted as "real engineering" by some students and faculty, it has been successful in attaining the University Core's designation for Diversity, Inclusion, and Social Justice – a requirement for undergraduates in all majors. This lower division course is meant as an introduction to social justice thinking and sets students up for Engineering and Social Justice (described below) that has students wrestle with these topics at a deeper, personal level.

B. Electrical Circuits

Electrical Circuits is a required EE class for EE, GE, and ME majors. It is typically taken in the fourth semester. In one section in Spring 2018 with 16 students, three modules were developed and incorporated to explore social context.

The first module, entitled "Conflict Minerals", included an interactive class experience and group presentations. Before this interactive class, students completed a homework problem where they estimated the amount of Tantalum (Ta) used globally in capacitors within smart phones and identified several countries where Ta is mined. During the discussion in class, the multidisciplinary instructor team introduced students to the definition of conflict minerals, conflicts in the Democratic Republic of the Congo (DRC) in particular, and the connection to capacitors, which were a previously stand-alone technical topic in class. Students were then encouraged to consider how they could minimize the use of conflict minerals as engineers. Ideas included recycling, reuse, optimizing designs, synthetic production, and researching alternative materials. For homework, each of the five student teams were assigned a different company to research. The next week, students presented their findings by describing products made by the company, where the company uses conflict minerals, the company's strategy for managing conflict minerals in their supply chains. Students concluded each presentation by critically evaluating these strategies. One student stated, "I thought it was a really interesting topic that has larger social consequences. It was cool to get away from the stigma of engineers only worrying about math and showing that engineering is able to have effect in other disciplines."

Later, students engaged in a second experiential module, this time visiting the Electronics Recycling Center (ERC) on campus to explore recycling and reuse of electronics. In their required reflections, seven of the 16 students commented that what stood out to them was the large amount of electronic waste generated in the USA. Most mentioned something about considering this waste in their future careers as engineers.

Near the end of the semester, a third module entitled "Responsible Social Innovation" was incorporated into the class. This module centered on the Sunshine Box [18], a product of 1773° Innovation Company that aims to provide safe and reliable solar power charging for cell phones in places that do not have stable electrical grids. The founder and inventor shared practical circuit diagrams with us, and for homework, students used what they had learned in Circuits thus far to calculate some key values for these circuits. Then, the founder came to class and shared her experiences and prompted students to think critically about responsible design considerations for engineered products. Students felt the experience was beneficial. One student stated, "The circuitry of the Sunshine Box was very interesting and applied some concepts learned in class to a larger real-life situation. The process of making electrical design decisions highlighted the importance of working with both the constraints and the users for effective and useful designs."

Highlights of the semester-long module integration experience for the instructor team included the enthusiasm that the students demonstrated as they engaged deeply with the topics of these modules. Students' insights were sophisticated and they saw tight conceptual relationship between the modules and the technical content of the class. They also understood these modules to enhance their experience learning about circuits. Challenges included deciding at what level to discuss the difficult issue of conflicts in the DRC, logistics of arranging for the ERC visit outside of class time, and finding aspects of the social innovation electronic circuit design that students in this introductory circuits class could understand well enough to perform calculations. As an added benefit, two of the students in the class got summer internships at the ERC.

C. Engineering and Social Justice

Engineering and Social Justice is a required class for GE majors in the third year and a potential elective for other majors. It was offered for the first time in Fall 2017 with 11 students including juniors in GE and seniors in ME.

In *Engineering and Social Justice,* students use critical literacy practices [19-23] to analyze the historical, social, political, and economic impacts of engineering in marginalized communities. Students consider the contemporary contexts and impacts of the designs, systems, processes and products surrounding and involving engineering and engineers.

At the foundation of the course lies the idea that in order to deconstruct dominant paradigms in engineering, it is necessary to analyze how engineering knowledge is constructed and used to perpetuate inequities [22]. Thus, a critical literacy approach is used to critique and transform dominant discourses in engineering and move toward a "dialogical model" [19] to understand engineering as a sociotechnical endeavor. Some of the activities used to achieve the goals of the course include critical reflection essays on topics of feminism and microaggressions; an analysis of the intersecting axes of privilege, domination, and oppression; and a community engagement project analyzed through the lens of Critical Race theory.

Some of the critical literacy strategies used throughout the course include problem posing/problem identification [24], where students locate, evaluate, and use different functional texts and community resources to clarify a problem that may not be evident or lacks context. For instance, the final project for the course involves working with community partners to frame problems that may be solved through engineering. Other activities include analyzing engineering multimodal texts, which combine two or more modes of communication such as written language, gestural, audio, visual, or spatial such as advertisements, sketches, designs, videos, and others [25]. These multimodal texts are analyzed through a series of questions, including: (1) who is missing in the text/picture/design/situation? (2) whose voices are represented and whose voices are discounted? (3) what are the intentions of the author and what does the author want me to think? (4) what would be an alternative to the narrative presented in this text/picture/design/situation? and (5) how can we use this information to promote equity? [24] The deep reflective nature of this approach engaged students in thinking about issues of power and oppression that may be inherently present in engineering practices and designs.

Students demonstrated some contradictory behaviors at the beginning of the course such as acknowledging that racism and biases impact vulnerable communities but not recognizing that racism and biases also impact the work that engineers do. Nonetheless, by the end of the course, students developed a high level of critical consciousness [26] that helped them become more aware of the sociotechnical nature of engineering and resituate their role as future engineers [27].

It is important to mention that not all students reached the same level of critical consciousness, and that developing this critical consciousness required a long process of reflection facilitated by the instructor through critical questioning [24]. Such process involved a reevaluation of their intolerance of uncertainty and their belief that rational behavior leads to solutions, which are deeply engrained perceptions within engineering [3]. Thus, critically questioning how engineering operates may be disconcerting and uncomfortable for some students. Although students indicated that the course posed some challenges because they had never taken a similar course in their engineering curriculum, they commented that the "course should be mandatory," and that the course "is addressing real world engineering issues more than any other class [they] have taken" [27].

D. Engineering Peace

Engineering Peace is an elective class for upper division undergraduate engineering students and undergraduate and master's students in Peace Studies. The first offering was in Fall 2017 with 24 students: 14 ME majors including 10 4th year students, two 3rd year students, and two 5th year students and 10 non-engineering students majoring or minoring in Peace Studies.

Engineering practice is inherently interdisciplinary. Current curricular structures, however, provide engineering students with few opportunities to work across disciplinary boundaries. In *Engineering Peace*, senior students from the Shiley-Marcos School of Engineering are brought together with master's students from the Joan B. Kroc School of Peace Studies. Students enrolled in Peace Studies typically have backgrounds in the social sciences and are studying ways to promote peace and justice throughout the world. These students were asked to work together on an interdisciplinary team of four to design a drone to have a positive impact on society. The course learning objectives focused on students' abilities in relationship to broader contextual issues, a bounded technical challenge and its social implications (building a drone), and their role in the process. One of the key goals 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.

To students the class was framed as an experiment – a chance to try out a new pedagogical approach to interdisciplinary education. It was unsure how students would react to this course, as courses integrating engineering and issues of peace and justice are often met with student resistance. One student remarked on the interdisciplinary nature of course "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?" In the end, these students proved quite 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).

While it is always nice to offer a class that students enjoy, far more important is what students actually learn. Assessment included student performance using both qualitative and quantitative methods, including thematic analysis of student work, focus group discussions, faculty reflections, ethnographic observations of the class, student surveys (pre/post). While this data is still being analyzed, preliminary results suggest most of the learning objectives were achieved. Students demonstrated both a clearer understanding of their disciplinary identity and recognition of the importance of integrating voices from outside of their discipline.

In end of semester focus groups, students described working in the interdisciplinary teams as a great benefit to their drone projects. In particular, they found early brainstorming, critique, and practical project planning benefitted from heterogeneous team composition. As one engineer remarked "… 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.'"

At its heart, this class focused on helping students understand that sustainability is a core tenet of the engineering process. Here sustainability is broadly defined following the 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." [28] Students from both engineering and the social sciences were helped to 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.

III. Summary

The authors are designing and implementing curricula to help develop Changemaking Engineers who see engineering as a sociotechnical endeavor. This includes modules, revised courses, and new undergraduate courses at all levels. Expanding engineering education beyond the narrow technical topics that are traditionally taught is challenging particularly for engineering instructors who have gone through a traditional engineering education themselves. The authors believe this work helps instructors and students achieve ABET outcomes related to social and global impact and is critically important to our students' long-term professional success and well-being in their future careers as engineers tackling difficult multidisciplinary real-world problems. It is the hope that others can benefit from learning about these shared experiences and will also work towards integrating social justice and peace within their engineering curricula.

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