Contextualizing a New General Engineering Curriculum in the Liberal Arts

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Abstract

Since its founding several decades ago, our School of Engineering has offered a BS/BA degree with an extensive liberal arts component. With support from a National Science Foundation IUSE/PFE: Revolutionizing Engineering and Computer Science Departments (IUSE/PFE: RED) grant, we are now integrating the liberal arts directly into our engineering courses in a new general engineering curriculum that reframes traditional engineering content around its broader societal contexts. Rather than focus on specific disciplinary knowledge students might need for a particular career, we are developing a curriculum focused on strengthening the critical skills common across engineering disciplines, such as design, analytical problem-solving, communication, and the ability to make interdisciplinary connections. In addition, we recognize that graduates must understand the profound social responsibility that comes with being an engineer. In alignment with the mission of our Catholic university, we are infusing our curriculum with a humanistic approach to engineering by orienting the core of our department around social justice. We plan to educate engineers that are able to integrate the appropriate perspective -- be it global, local, environmental, or social -- into the engineering decision-making process. In this paper, we describe the founding of our new department and describe the institutional context that made it possible. We also lay out our proposed curricular structure and discuss several courses currently under development.

Introduction

At an alumni panel for first year engineering students in Fall 2016, we listened as recent graduates reported working in engineering jobs where they "did not use" their mechanical, electrical, or industrial engineering degrees. Upon further explanation, the alumni clarified that what they meant by this statement was that they did not use their disciplinary expertise. They did, however, emphasize the ways that the abilities they acquired in their engineering education -- namely technical problem solving, critical thinking, communication, and teamwork -- were what allowed them to succeed as engineers. To the surprise of our current students, the panelists all agreed that one of the most useful classes they took was public speaking. Recognizing the need for a broad curriculum that reflects the diversity of skills engineers require, including those within the liberal arts, we have started a new major in General Engineering. In this paper we describe the design of the new general engineering curriculum at the University of San Diego.

The argument for an engineering curriculum with a broad foundation that includes the liberal arts is not novel. Just after the creation of the National Science Foundation (NSF) in 1955, the Engineers' Council for Professional Development commissioned a study to investigate how engineering education could keep pace with rapid developments in science and technology. The result of this study was the influential Grinter report[1], among whose recommendations included an emphasis on the importance of integrating liberal arts into engineering education. While the report argued for balance between the technical and liberal arts, few current engineering programs have achieved this balance. Peden, a division director at the NSF and Professor of

Electrical Engineering, points out in her reflection on the report: "The committee did not foresee the selectivity the academic community would apply in implementing the goals articulated in the report, which itself offers a balanced view of the technical and social objectives of an engineering education..." [1] The imbalance remained even in 2003, when Williams, then director of the program in science, technology, and society at Massachusetts Institute of Technology, argued that "cramming more and more into the engineering curriculum runs in exactly the wrong direction,"[2] and in 2008, when Duderstadt, Professor of Engineering and former President of the University of Michigan, identified the need for "highly interdisciplinary engineering teams characterized by broad intellectual span rather than focused practice within traditional disciplines." [3] As Wisnioski points out in 2015, engineers assert year after year that we are "struggling to meet the challenges of a global society dominated by technology,"[4] but such a vision has yet to come to fruition. This stagnation is exactly the intractable problem the NSF IUSE/PFE: Revolutionizing Engineering and Computer Science Departments (hereinafter referred to as RED) program was designed to address.[5]

This paper discusses the development of an engineering program that takes the Grinter report one step further. The fifth recommendation of the Grinter report explicitly advocates for "a continuing, concentrated effort to strengthen and integrate work in the humanistic and social sciences into engineering programs."[6] Not only do we integrate liberal arts into engineering, and frame the technical by its broader social contexts, but we also take a humanistic approach to engineering by orienting the core of our department around social justice.

With the assistance of an NSF RED grant, we at the University of San Diego are developing a plan for educating "Changemaking" engineers. We are developing a novel curriculum that infuses the contexts of social justice, peace, humanitarian advancement, and sustainable practices directly into engineering courses. We hope that by explicitly integrating these themes into our educational process, we will produce graduates who understand the profound social responsibility engineers hold in shaping society. If we can demonstrate the success of this approach within our own institution, we hope to develop transferrable content modules from our courses that can be similarly infused in curricula across the nation. In this paper, we outline the approach we are taking to forming our program, some reasons for our success thus far, some details of our program and examples of proposed courses, and some challenges we face.

General Engineering at University of San Diego

The creation and success of our program thus far has been largely due to an outpouring of institutional support. As a value-based institution, the University of San Diego (USD) has integrated our Catholic mission, public purpose, and commitment to the liberal arts with an initiative to create positive social impact. USD brands itself as a "contemporary Catholic institution" that views peace and justice as inseparable from education, scholarship, and service. This sets a framework not only for our department, but as the vision of the university. USD is also one of only 37 colleges and universities in the world that are designated as an Ashoka U "Changemaker Campus"-- a recognition of our university's commitment to finding sustainable solutions to the world's most pressing problems. As a realization of this purpose, USD has launched a Changemaker Hub which serves as a platform for creating changemaking

opportunities that bring together faculty, students, and staff from across campus. We have recently hired a new president and are in the process of implementing a new strategic plan, "Because the World Needs Changemakers", aligning university-wide curricula with the values of our institution. This new strategic plan identifies six interconnected pathways that the university will pursue: becoming an anchor institution, demonstrating engaged scholarship, practicing changemaking, advancing access and inclusion, demonstrating care for our common home, and integrating the liberal arts education.

The integration of university values is also reflected within the engineering school itself. The Shiley-Marcos School of Engineering awards only joint BS/BA engineering degrees, requiring graduates to have a robust education in both engineering and the liberal arts thereby establishing a tradition of valuing the holistic education provided in such a context. Many engineering faculty are supportive of integrating changemaking into the curriculum although the concepts of what this entails vary. The leadership team of the school is clearly committed to educating changemaking engineers and are the principal investigators on the RED grant. This includes the Dean, Associate Dean, and three department chairs. This broad support, reflected throughout leadership and the faculty at large, has resulted in the creation of the new general engineering department as well as several new faculty hires (including the authors of this article). Although the general engineering (GE) department was approved by the university before the RED grant was awarded, the grant has helped to shape the focus of the GE program and provided resources for its development.

In addition to institutional support, we have also connected with a growing network of engineers that are interested in social justice. The organization Engineering, Social Justice, and Peace (ESJP) hosts an annual conference and publishes a journal that focuses on these issues. As described on their website, ESJP seeks "to better understand the relationships between engineering practices and the contexts that shape those practices, with the purpose of promoting local-level community empowerment through engineering problem solving, broadly conceived."[7] This community has been instrumental in informing our curricular design and the founder of ESJP has joined us as a professor of praxis within the new General Engineering department.

Program Structure

The General Engineering major was officially added to the the university catalog in Spring 2017. However, as students do not begin taking major-specific courses until after they complete the common engineering core, our first course will be offered in Fall 2017. We anticipate that our program will be ABET accredited under the Engineering (general) category after we confer degrees upon our first graduates in 2019.

Our GE curriculum is divided into four components: university liberal arts requirements, an engineering core, GE major courses, and a concentration. This results in a 4.5-year program for the typical engineering student. Table 1 shows an example curriculum for a general engineering student with an undefined concentration.

The engineering core, common across all engineering majors at USD, consists of four introductory classes that introduce students to the different fields of engineering, the design process, and programming. This engineering core is complemented by approximately 10 liberal arts courses that are required for all University of San Diego graduates. Note that Table 1 shows these liberal arts university requirements (UR) in no particular order.

We have planned 12 GE major courses to give students broad exposure across multiple fields of engineering. We are initially developing only a few of these courses, four of which are described in more detail below, which will focus on integrating social justice and societal context with technical content. The remaining courses are temporarily offered in their traditional contexts by the other engineering departments at USD.

The last part of the degree, the concentration, is a 9-course sequence that builds upon earlier coursework. The option of choosing a concentration gives students flexibility, autonomy, and depth in their curricular interests. This structured set of courses is clustered around a particular topic. Departments both within and external to the School of Engineering can propose concentrations as our hope is to facilitate integration across disciplines. The concentration component of the program may also serve as an incubator for future majors, in which successful and popular concentrations may diverge into stand-alone departments. The first concentration we have launched is Embedded Software, developed collaboratively with the Computer Science department. Other concentrations currently under development include Bioengineering, Sustainability, Social Justice, and Law.

An alternative to choosing a concentration is for students to design an independent program of study (IPS). This flexibility is built into the curriculum to support endeavors in interdisciplinary careers or even those external to engineering, such as medicine. While there are multiple pathways that students can take through the curriculum, all of the versions will satisfy ABET criteria.

Table 1: Example curriculum plan

Semester 1 Calculus I EC: Introduction to Engineering EC: Engineering Programming UR: First-Year Writing UR: Historical Inquiry	**Semester 2** Calculus II General Chemistry I Introduction to Mechanics EC: Intro to Electromechanical System Design UR: Social and Behavioral Inquiry
Semester 3 Engineering Math Introduction to Electricity & Magnetism EC: User-Centered Design UR: Artistic Inquiry UR: Language	**Semester 4** Calculus III GE: Energy: Generation, Transfer, and Impacts GE: Statics GE: Electrical Circuits GE: Software Foundations
Semester 5 GE: Engineering Probability and Statistics GE: Engineering and Social Justice GE: Engineering Materials GE: Digital Design Concentration Course	**Semester 6** GE: Experimental Engineering GE: Sustainability and Engineering Concentration Course Concentration Course Concentration: MATH/SCI
Semester 7 GE: Senior Design Concentration Course: Engineering Concentration Course UR: Ethical Inquiry UR: Theological and Religious Inquiry	**Semester 8** GE: Senior Design Concentration Course: Engineering Concentration Course UR: Theological and Religious Inquiry UR: Philosophical Inquiry
Semester 9 Concentration Course UR: Literary Inquiry Free electives	

Note: EC = Engineering Core, UR = University Requirement, GE = General Engineering major course

In a 2003 paper, Newberry and Farison categorize and define three types of general engineering programs in the United States.[8]

- *Philosophical* programs are broad by intention, under the philosophy that a general education has intrinsic advantages over discipline-specific programs;
- *Instrumental* programs are often temporary and designed to later transform into one or more discipline-specific options; and
- *Flexible* programs often complement discipline-specific programs to allow students to tailor their own intra- or interdisciplinary educational experiences.

We believe our three-part curricular structure is the first of its kind in the United States by deliberately creating a hybrid of all three existing GE program models. Our major courses are developed around social contexts, program outcomes, and engineering skills rather than disciplinary content, following the *philosophical* program structure in the lower division. Rather than maintain the same model throughout the curriculum, the upper division coursework builds

upon the major courses in a different way: concentration tracks are designed to be *instrumental*, and the IPS track is designed to be *flexible*.

One important aspect of our program structure is that, with the addition of just five courses, a new major has been created by initially "piggybacking" off of the existing disciplines. While we build our GE courses, much of our curriculum leverages technical coursework (e.g., Statics, Electrical Circuits) taught in other departments. However, the long term goal is to house all GE courses within the department for two reasons. First, we aspire to transform traditional engineering content to be explicitly tied to their broader contexts and social impacts. Second, we pragmatically aim to be self-sufficient to minimize the demands placed on other engineering departments by our students. The short-term strategy for this small-scale development of our curriculum is not only vital, but also advantageous. While most would agree that contextualizing traditional engineering content is both important and effective, there is tremendous inertia to overcome to successfully integrate this context across an entire curriculum. By cultivating a social mindset in our GE-specific courses, we can help students see the impact of engineering on society as they engage in their technical coursework, without requiring systemic change across all existing majors. If integration across the general engineering curriculum has the desired impact, we hope other faculty will see the benefits and integrate it into their courses of their own accord. Modules developed in the GE program will hopefully facilitate this.

Program Outcomes: Designing a Curriculum around Criteria for Student Success

As discussed by Bowden, engineering curricula have traditionally trained students to recognize algorithms as tools, yet these tools are not useful if "learned in isolation so that graduates are unable to work out when and how to use them to deal with real-life problems."[9] This gap between learning how to use tools and how to apply them is called by many names: technical and social, intellectual and pragmatic, hypothetical and real-world, philosophical and practical, etc. Our program aims to prevent this disconnect by contextualizing engineering through the lens of societal and global challenges.

As an alternative to content-driven curricula, Baillie et al. propose that adopting a *threshold capability* focus. This curriculum approach cultivates students' ways of thinking and being and can help develop more independent and critically thoughtful engineers.[10] To design such a curriculum, the first step is to define overall program goals. With these in mind, specific course goals, learning experiences, and then teaching plans are developed. By focusing on graduates' abilities, this approach to curricular design provides a framework seemingly built for *philosophical* general engineering programs. While the objectives of our program outcomes include demonstrating transferable engineering skills and mindsets, such as confidence in tackling cross-disciplinary open-ended design problems, the specific outcomes are still under development. One of the objectives of this paper, submitted as a work in progress, is to solicit feedback from the community about how we should define our program outcomes.

Motivated by the mission to "revolutionize engineering", particularly at a Catholic institution, the heart of our curriculum is heavily rooted in helping students understand "engineering for humanity". While not quite humanitarian engineering (understood to involve development

projects) nor purely social justice, our program aims to capture the essence of *evoking individuals' values and the principles they uphold in relation to the work engineers do*. We explore the broader context of engineering problems while instilling a sense of duty and ethics, all the while still providing the technical skills engineers need to be successful.

Courses

The challenge in realizing our programmatic vision, as with any curriculum development, is executing these big ideas and program goals in teaching. Below we describe four select courses currently in development, one from each year of the program, that showcase our initial thoughts of how we will practically integrate social justice and broader contexts into the course material. Note that the first year course is for all engineering students, not just GE students. As such, it is being developed by faculty within and outside GE.

1st Year: User-Centered Design

One major challenge that engineers universally face is the disconnect of their work from its users. In this first year class, we stress that designs cannot be based simply on the designers' own understanding, and we emphasize the need to develop empathy for users, who may have different assumptions and experiences. In an effort to better integrate social justice into engineering, this course aims to help students understand their own privileges, which we achieve through reflection journals, activities such as a trip to a local museum with an exhibit on race, and classroom discussion. The course project entails a community immersion experience where students spend several hours throughout the semester working alongside community partners (such as at the local senior center or middle school) to build relationships with people with different experiences from our college students. The students then design an engineering innovation with input from this community as their final project. Our goal is to help students recognize that because their inherent biases can often be reflected in their work, empathy and understanding are crucial for developing meaningful engineering solutions.

2nd Year: Energy: Generation, Transfer, and Impacts

Our second year class focuses on the intersection of energy and society. This class will introduce fundamental concepts from thermal sciences (e.g., temperature, laws of thermodynamics, heat transfer, fluid mechanics). Rather than following a traditional textbook, however, we plan to develop problem-based learning modules that highlight the complex interplay between engineering, energy, and society. One module in the course will be based on the Carlsbad Desalination Plant, the largest desalination plant in the western hemisphere. This plant, located less than 30 miles from our campus, affords rich opportunities to investigate a wide range of issues: how energy is generated for the plant, the fluid mechanics associated with desalination, societal issues regarding drought and water conservation, the impact of global warming, and many others. The primary objective in this class will be to help students make connections between the theoretical aspects of engineering (such as the first law of thermodynamics) and the impact engineering decisions have on society.

3rd Year: Social Justice and Engineering

This class focuses explicitly on the ways in which engineering decisions and designs have

profound impact on social justice. As a discussion-based class, students explore sensitivity and inclusivity towards different forms of diversity, develop the ability to critique the historical function of engineering, as well as understand the environmental, social, and economic context in which engineering is practiced. The course develops in students a critical ability to question 'common sense' assumptions in dominant engineering discourse. The semester will culminate in a project where students attempt to deconstruct and critique existing engineering practices and begin to develop alternative just solutions.

4th Year: Senior Design

As with many engineering programs, our curriculum culminates with a year-long senior design experience. We plan to work with community partners to identify areas in which engineering can be applied locally in a meaningful way. The scale of these projects will allow students to apply their technical skills while keeping a critical eye on the potential influences their solution may have on various stakeholders. While recent graduates usually have little opportunity to engage with the broader context of their work, we recognize that many of our students will eventually move into positions of power. (Over 30% of Fortune 500 CEOs have a degree in engineering.[11]) By designing the capstone experience to both incorporate the larger societal context and require mastery of engineering design, we hope to prepare our students for multiple phases of their careers.

Potential Challenges

As we have reflected on our program and discussed this idea with colleagues, several challenges have become apparent. In this section we address what we currently see as the largest obstacles at this point.

Faculty Resistance to Change.

The main strategy we have used to overcome the inertia preventing change is by creating a new department to model and implement this curriculum. Faculty have not been pressured to contribute to this department; rather the department is composed of new hires and transfers of faculty who are interested in integrating social context and values throughout the curriculum. Our hope is that by first modeling this behavior within the GE department, we can convince others to follow our lead by demonstrating the success of the approach with our own students.

Contextualization is Challenging.

The idea of contextualizing classes is not a new one, but it remains one of the most challenging aspects of implementing such a curriculum. In particular, it means that to stay relevant course content must be constantly updated and refined as political and social contexts evolve. Our approach to this problem is to work collaboratively, both across the faculty and across the community. For instance, we are developing courses that are co-taught between engineers and social scientists.[12] We are also developing relationships with community partners, such as local primary and secondary schools, that inform our classes and towards which we can contribute our engineering knowledge. These cross-boundary partnerships are instrumental in identifying the relevant contexts for our courses and projects.

Can this model be used elsewhere?

We recognize that the vision we have laid out leans heavily upon our unique vantage point within our university. Rather than advocating for the imitation of our local institutional culture, we think the broader themes we have identified -- alignment of values, creation of a new program, and a focus on "engineering for humanity" -- are viable strategies for affecting institutional change. For example, Dr. Juan Lucena and Dr. Jessica Smith, at the Colorado School of Mines, are demonstrating the value of aligning their Humanitarian Engineering program with the desire of university stakeholders to promote socially responsible engineering. The Colorado School of Mines has strong ties to the extractive industries, which have been at the forefront of the corporate social responsibility (CSR) movement as these industries seek to garner and maintain the social license to operate. The Humanitarian Engineering program has been able to embrace the energy within the industry to integrate projects related to CSR into their curriculum, which has resulted in the generation of external financial support, internal institutional support, and program growth.[13,14]

Once we have demonstrated success in our local context, our goal is to produce learning modules that are transferable to other institutions. We hope that these modules reduce the complexity for other faculty attempting to integrate concepts from social justice into their own curriculum.

Conclusion

As a new General Engineering department at the University of San Diego, we are in the process of developing a curriculum that integrates social context, social justice, and social responsibility into our engineering courses. By leveraging multi-level institutional interest and support for "revolutionizing engineering", we aim to create a program that empowers students to understand the profound impact engineers can have on society. While our program structure at a values-based institution is unique, we believe our approach to integrating the social context of any local community has potential for transforming engineering programs. Our mission is to create a general engineering program deeply rooted in the liberal arts that graduates Changemaking engineers.

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