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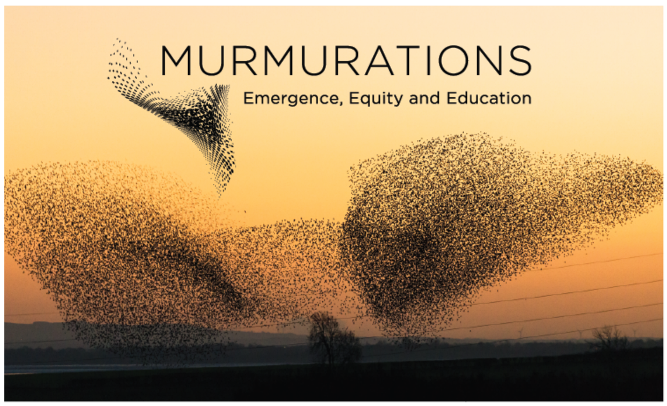




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ARTICLE

# Broadening the Engineering Canon: How Culturally Responsive Pedagogies Can Help Educate the Engineers of the Future

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## Abstract

Point of view: We are a diverse group. Three of us are pre-tenure faculty members in a newly founded Integrated Engineering department that seeks to develop a more holistic and inclusive engineering pedagogy with SML as the only tenured (full) professor. The fifth member of our team, and lead author, joined us in this endeavor while pursuing a Master's in Peace Studies. BM is a Black male born in Cameroon with a background in the social sciences. GDH is a White male born in the USA who seeks to use this unearned privilege to help change the culture of engineering. DAC is an Asian-American woman born to immigrant parents in the USA, and aims to articulate issues of social justice as a relatively privileged person of color through inclusive pedagogical techniques. JAM identifies as Mexican American/Latino, was born in the USA but raised in rural Mexico, and conducts research related to knowledge construction in sociocultural contexts, social justice, and asset-based approaches in engineering education. SML is a White woman born in the USA with degrees in engineering who has been in academia for several decades whose scholarly work focuses on engineering education research. Working on this team has convinced us of the importance of ensuring that such diversity in engineering teams becomes the norm rather than the exception.

Value of submission: The intent of this article is to encourage the engineering education community to look outside of the traditional engineering canon for pedagogical inspiration. We examine a collection of culturally responsive pedagogies and describe both incremental and radical approaches we use to include these in the engineering classroom.

Summary: Within engineering, Western, White, masculine, colonial knowledge has historically been privileged over other ways of knowing. Few engineering educators recognize the impact of ethnocentricity and masculinity of the engineering curriculum on our students. In this paper we argue for a new approach, one which seeks to create an engineering curriculum that recognizes the great diversity of cultural practices that exist in the world. We begin by reviewing key ideas from three pedagogies not typically incorporated in engineering education: Culturally Relevant/Responsive Pedagogy, Culturally Sustaining Pedagogy, and Indigenous Pedagogy. We then present our attempts to develop an engineering curricula informed by these practices. We describe interventions we have tried at two levels: modules within traditional engineering sciences and entirely new courses. We aim to persuade readers that these pedagogies may be a key tool in changing the dominant discourse of engineering education, improving the experience for those students already here, and making it more welcoming to those who are not.

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## Introduction

The engineering classroom has historically been a place focused on technical problem solving. For example, students are often asked questions such as "How large is the safety factor? What are the units on that calculation?" Students spend hours working on narrowly constructed homework problems that have a single correct answer in the back of the textbook. Practicing engineers, however, soon discover that engineering is not nearly so straightforward. Real engineering problems are messy primarily because engineering is about solving problems for and about people. People have different backgrounds, competing interests, and a host of other qualities that are not easily captured by a single number with appropriate units. Engineering problems do not occur in a vacuum, they happen amid complex social, ethical, political and environmental forces (Miñano et al. 2015). To be successful in solving these problems, engineering students must learn to understand the complex cultures, ways of living, and ecosystems in which engineered systems exist (Baillie and Catalano 2009).

Unfortunately, the current state of engineering education fails to address these global needs. Over a decade ago, in her book *Engineering and Social Justice*, Riley noted that engineering has historically served "an ever-expanding materialistic and militaristic culture" while staying unresponsive to public concerns (p. IV, Riley 2008). Fast forward to 2014 and Cech, a sociologist who studies engineering, found that undergraduate engineering programs may actually be training students to care less about social issues than when they started college (Cech 2014). Given that engineers work in large complex technical systems, Cech notes that this disengagement "may help reproduce an unequal status quo, and perpetuate—or even exasperate— existing disadvantages for groups within that public" (p. 65, Cech 2014).

We agree with these scholars that engineering education has struggled to confront its own sociotechnical nature. To prepare the engineers of the future, we argue that engineering faculty must work to revolutionize engineering education. Educational responsiveness to the continuously changing context of engineering education requires instructors to understand and recognize the changing world of engineering. This practice requires an ability to develop students academically while nurturing and supporting cultural competence to help them develop a socio-political consciousness (Ladson-Billings 1995). Furthermore, as globalization continues, engineers trained in the U.S. are more likely to interact with people and issues from different cultures, geographies, and government regulations (Mariasingam et al. 2007). As the Newport Declaration to Globalize U.S. Engineering Education notes, "IT IS IMPERATIVE that all engineering students develop the skills and attitudes necessary to interact successfully with people from other cultural and national environments" (p. 23, Grandin and Hirleman 2009). The next generation of engineers will not only need more technical skills, but they will also need to be exposed to new spheres of knowledge (Maher 2003).

Engineering is often viewed as objective and independent of culture. Scholars argue that in reality engineering has a dominant discourse – one that privileges, Western, White, masculine, colonial knowledge over other ways of knowing. This dominant discourse encompasses the beliefs, myths, values, rituals, and even curricula that give meaning to the "ways of being" an engineer and to the profession. As a result, the inherent ethnocentricity and masculinity of the engineering curricula substantially impacts problem definition and accepted methods of problem solving, teaching, and assessment (Riley 2008; Baillie and Catalano 2009; Leydens and Lucena 2017). This dominant discourse also ignores potentially useful knowledge and devalues the lived realities, perspectives, and epistemologies of those who do not fit into the dominant category. To create an inclusive engineering curricula for more students, engineering educators need to recognize and address this systemic bias. By learning from other worldviews and ways of knowing, engineers have an opportunity to promote learning in ways that are meaningful and relevant while challenging deficit models (Valenzuela 1999; Valencia 2002, 2010). This problem cannot be addressed by simply recruiting more students or faculty of color (Chen, Mejia, and Breslin 2019). We argue here for an alternative curricular approach that draws from a collection of pedagogies that take a critical eye towards linguistic, literate, social, and cultural hegemony.

In the 1990s, several pedagogical approaches emerged to broaden the perspectives of students in American schools. In this paper we focus on three culture-centric approaches: culturally relevant/responsive pedagogy (CRP), culturally sustaining pedagogy (CSP), and indigenous pedagogy. Ladson-Billings' Culturally Relevant Pedagogy (CRP) has been adopted in K-12 education across the United States as a means of including the perspectives of racial minority students into education (Ladson-Billings 1995). The idea that culture and heritage can help improve and expand student's perspectives has been echoed by many Culturally Sustaining and Indigenous Pedagogy theorists (Paris 2012; Tuck and Yang 2012; McCarty and Lee 2014; Marin and Bang 2015; Paris and Alim 2017).

While these pedagogies were originally developed for the benefit of minority students, and should continue to be used as such, we argue engineering educators can learn from these approaches to help broaden their mindsets and the mindset of all students, especially in fields like engineering that are centered around Whiteness. There is evidence that these approaches can help challenge simplistic conceptions of multiculturalism and address fears that these will somehow negatively impact White students (Sleeter 2012). Research that documents the impact of these asset-based approaches, including exploring how instructors can learn how to use them in their classrooms, is necessary. Engineering, like culture, is a complex blend of social and technical practices and experiences; thus, students should be taught to recognize this complexity.

A cautionary note: adopting these pedagogies is not a panacea. A critique of these pedagogies is that some educators simply pay lip service to these practices to check diversity boxes, rather than to enrich and expand the perspectives and experiences of students (Sleeter 2012), or of instructors themselves. Engaging in these pedagogies is a journey and relies on constant critical reflection, collaboration, and the willingness to challenge the curricularization of dominant discourses. Our program seeks to graduate individuals who serve as catalysts for change in their future communities. We hope to train engineers who can provide sociotechnical solutions – those that recognize and honor both the social and technical elements of a problem (Hoople and Choi-Fitzpatrick 2020). Using these pedagogies, we hope to change the dominant discourse, improving engineering education for those students already here and making it more welcoming to those who are not.

In this article, we first present an overview of several culture-centered pedagogies followed by a roadmap for change. We explore the ways in which we are integrating these pedagogies into our own teaching, and present approaches for working within the system as well as our attempts at more radical change. We hope this article will serve as a jumping off point for faculty looking for ways to change the system in which we reside.

## Culture-centered Pedagogical Approaches

In this section, we briefly examine three culture-based approaches to pedagogy: Culturally Relevant/Responsive Pedagogy, Culturally Sustaining Pedagogy, and Indigenous Pedagogy. Despite their differences, these three approaches are all built on the foundation that education should consider (and celebrate) the cultural diversity across the globe and recognize rather than annihilate (or assimilate). Each approach has a rich history that cannot be fully captured in this short overview. We encourage readers to dig further into the literature starting with the citations provided.

While these pedagogical approaches have been successful in different settings, they have also failed in contexts where the instructor has failed to acknowledge cultural bias or in spaces where institutional support for implementation is absent (Young 2010). It is important to point out that the work presented here requires more than just a collection of techniques. It involves engaging in conversations that may be difficult, participating in continuous critical reflection, challenging dominant discourses, and drawing from different approaches to create a truly student- and culture-centered educational space. At the end of this manuscript, we provide some reflections on our own progress towards adopting these pedagogical approaches.

### Culturally Relevant/Responsive Pedagogy

Both Culturally Relevant and Culturally Responsive Pedagogies seek to counter the neoliberal models of school reform—including high-stakes testing, increased assessment and school choice (Brathwaite 2017), as well as the treatment of schools as businesses with clients, which opposes education's original goal of democratization–by integrating what are known as asset-based pedagogies (Jackson and Boutte 2018). Gay defines culturally responsive pedagogy as "using cultural knowledge, prior experiences, frames of reference, and performance styles of ethnically diverse students to make learning encounters more relevant and effective for them. It teaches to and through the strengths of these students" (p. 31, Gay 2010). Culturally Relevant Pedagogy (CRP) was first described by Gloria Ladson-Billings in the 1990s as "a pedagogy that empowers students intellectually, socially, emotionally, and politically by using cultural referents to impart knowledge, skills, and attitudes" (Ladson-Billings 1995). As classroom diversity increases across the United States, there is a need for scholars and educators to learn from, not merely about, minoritized students (Ladson-Billings 2014). CRP is built on three key pillars:

1. Student achievement and learning: Educators should strive to ensure that all students succeed academically.
2. Cultural competence: Educators should help students to develop or maintain cultural competence.
3. Socio-political consciousness: Students should be encouraged to challenge the status quo of social order and solve socio-political issues that affect their communities (Ladson-Billings 1995).

Howard notes that for teachers to fully utilize CRP, they have to reflect critically on their own racial and cultural identities (Howard 2003). This entails reflecting on questions such as "How frequently and what types of interactions did I have with individuals from racial backgrounds different from my own growing up? Who were the primary persons that helped to shape my perspectives of individuals from different racial groups? How were their opinions formed? Have I ever harbored prejudiced thoughts towards people from different racial backgrounds?" (p. 198, Howard 2003). Brown-Jeffy and Cooper echo the importance of race in CRP, noting that CRP is not just about considering racial diversity during specific periods like Black History Month, but infusing it into the whole academic process (Brown-Jeffy and Cooper 2011).

There is evidence that CRP can improve performance and student engagement in science, technology, engineering, and math (STEM) fields. In 2016, Aronson and Laughter wrote a comprehensive piece on the positive impact of CRP in schools across the United States (Aronson and Laughter 2016). They cite the work of Tate who was able to make high school mathematics lessons more practical and relevant by incorporating problems that African American students face (Tate 1995). By working on a class project aimed at relocating liquor stores located within 1,000 feet of their institutions, students gained a better understanding of tax codes and fiscal incentives. They then used this information to "think about mathematics as a way to model their reality" (p. 170, Tate 1995). Not only did this improve their math proficiency, but it also increased their engagement in the classroom. Other examples in mathematics education include Civil and Khan (2001), González et al. (2001), and Razfar (2012). Examples of CRP in science education include Dimick (2012), Grimberg and Gummer (2013), and Lee and Buxton (2013).

In higher education there has been little integration of these techniques into the classroom, though some attempts have been made to include such approaches as extracurriculars. In one study, Mejias et al. report that the introduction of culturally-relevant practices in Howard University's Computer Science Department improved student engagement and participation (Mejias et al. 2018). Instructors in the department took actions such as creating awards for students' social and community achievements out of the classroom. Student retention increased from 66% to 94% between 2012 and 2016 while enrollment and student academic performance also increased significantly.

## Culturally Sustaining Pedagogy

Paris defined Culturally Sustaining Pedagogy (CSP) as an educational approach which "seeks to perpetuate and foster—to sustain—linguistic, literate, and cultural pluralism as part of the democratic project of schooling" (p. 63, Paris 2012). CSP is opposed to deficit approaches to education which seek to eradicate linguistic, literate and cultural practices which students of color bring from their communities. Paris and Alim argue that closing the so-called "achievement gap" is not just about getting working-class students of color to speak and write like middle-class White ones – it requires centering pedagogies on heritage and practices of students of color (Paris and Alim 2017).

What distinguishes CSP from other asset-based pedagogical philosophies is its emphasis on the changing nature of culture. Paris and Alim note that many asset-based pedagogies focus too much on heritage and the historical elements of students' culture ignoring contemporary practices that are dynamic and ever-evolving. Like Gutiérrez and Rogoff (2003), Paris notes that it is incorrect to assume that culture is equivalent to ethnicity, language, or national origin. Hence, educators should strive to understand the current practices of students—ways of talking, leisure activities, etc.—and find ways to sustain these within the educational system (Gutiérrez and Rogoff 2003). For instance, working with youth in a California high school, Paris and Alim found that Mexican youth navigated their identities by participating in Hip Hop cultural practices while "simultaneously participating in their own heritage practices (like clothing and ways of believing) passed down from the elders in their ethnic communities" (p. 91, Paris and Alim 2014). In the STEM context, Jett has used CSPs in his mathematics classroom. "Africana mathematics draws from different dimensions to showcase the mathematical contributions of African American scholars as well as other marginalized scholars of color" (p. 106, Jett 2013).

## Indigenous Pedagogy

Indigenous pedagogy seeks to recognize indigenous knowledge that is different from Western conceptualizations of science or mathematics and involves a more "participatory, experiential, process-oriented, and ultimately spiritual process" (p. 36, Michell 2005). In the United States context, Indigenous Pedagogy focuses primarily on methods and practices of teaching Native American students while drawing from indigenous knowledge. McNally describes four characteristics of indigenous pedagogy: (1) oral tradition (as opposed to book "knowledge") as a way to develop relational and situational construction of knowledge, (2) knowledge is to be used for the benefit of the community and their well-being, (3) knowledge construction involves experiential learning, and (4) holistic reflection (McNally 2004).

Historically, Western-based educational spaces have altered, excluded, and sometimes rejected values, beliefs and knowledge systems present in indigenous knowledge (Garcia and Shirley 2013). These practices, perpetuating colonial traditions, have lead some scholars to call for education to be "decolonized." We have begun to facilitate discussions of decolonization in engineering education (Lord, Mejia, Wolmarans, et al. 2019; Lord, Mejia, Hoople, et al. 2019). Tuck and Yang argue that decolonization of education cannot be confused with other pre-existing anti-racist, social justice, or critical frameworks (Tuck and Yang 2012). Rather, true decolonization goes beyond surface education reform or actions aimed at freeing the mind. It requires rebuilding a school system that will confront the colonizing practices of education and curricularization. It also requires a change of world order and the repatriation of land to sovereign Native tribes. McCarty and Lee hold a similar view (McCarty and Lee 2014). They assert that the sovereignty of Native Americans predates the U.S. constitution. Hence, schools should be accountable not only to federal governments but also to the Native American nations whose children they serve. They note that schools can revitalize indigenous communities by:

- Considering asymmetrical power relations as well as Native Americans' struggle for self-determination;
- Reclaiming and revitalizing what colonization has disrupted – for example using Native languages (as opposed to English) in educational settings; and
- Focusing on community-based learning (McCarty and Lee 2014).

With regards to indigenous science education, Marin and Bang note that Native science and Western science are not incompatible (Marin and Bang 2015). To them, there is a need to understand the relationship between places where curricula are enacted and how they stand in relation to indigenous epistemologies.

We provide a summary of the three culture-centered pedagogical approaches in Table 1 for the convenience of our engineering audience. The nuances between the pedagogies, however, are not well-captured by a table, and the differences should not and cannot be reduced to these few items. As such, we encourage the readers to immerse themselves in the literature.

**Table 1. Culture Centered Pedagogical Approaches.**

| Culturally Relevant/ Responsive Pedagogy | Culturally Sustaining Pedagogy | Indigenous Pedagogy |
|---|---|---|
| •Seeks to ensure the academic success of students | •Seeks to sustain, rather than eradicate, the cultural ways of being and linguistic practices of communities of color | •Embraces "wisdom-in-action" (i.e., a journey toward wisdom related to human action) |
| •Embraces the development of cultural competence | •The ways of knowing, doing and being of communities of color are legitimate and valid | •Is participatory, experiential, process oriented and spiritual in nature |
| •Encourages the development of critical consciousness | •Relies on asset-based pedagogical research that opposes deficit-framed policies and practices | •Promotes land-based and intergenerational knowledge construction |
| | | •Highlights the importance of narrative (storytelling) and holistic reflection |

## A Possible Roadmap for Change?

Broadly speaking, the pedagogies discussed previously help students by sustaining contemporary cultural perspectives in the classroom. Not only do they increase student engagement, but they also enable students to make links between abstract theories and contemporary challenges in their communities. As we think about training the next generation of engineers, the ability to see the connections between engineering concepts and society's greatest needs is of paramount importance. The authors of this article have founded a new department, Integrated Engineering, aimed explicitly at helping students make these connections. The educational objectives of our department (Department 2020) are to graduate students who:

- are equipped with an interdisciplinary set of technical, leadership and other professional capabilities necessary to understand and address problems in local and global contexts,
- practice engineering with a critical understanding of how engineers engage with and impact society,
- have a critical awareness of their personal attitudes, behaviors and values and the ways in which these align with their professional aspirations.

Here we describe how we have started to change our own pedagogical approach. This is not an easy process and requires substantial introspection and self-reflection, but hard work is needed if we are to shift the incredibly entrenched status quo of engineering education.

### Small Steps Toward Change: Reflexivity in Engineering Sciences

We started this journey by making small changes in "standard" engineering classes. Here we describe interventions we have tried in middle year classes including statics, thermodynamics, and circuits. One obstacle faced in these attempts was the feeling that there is no space to add anything new into these already packed courses. This is a prevalent challenge within engineering, where second and third year engineering science courses have become akin to sacred texts (Lord and Chen 2014; Lucena 2015). Recent research across all majors suggests, however, that for a large proportion of college graduates their "gains in critical thinking, complex reasoning, and written communication are either exceedingly small or empirically nonexistent" (p. 121, Arum and Roksa 2011). We argue that in every class there are at least a few minutes where it is possible to try something different. By taking time to bring in context that connects the material more directly to students, there is an opportunity to increase learning while better preparing students for the messy problems they will face in their careers.

### Statics

Many students take Statics as their first engineering science course. Author DAC has worked to contextualize the material by presenting Statics concepts within the dynamic and ever-evolving sociocultural practices students are more likely to have encountered (e.g., paddle-boarding, backpacking, or even a car door getting stuck on the curb) than the random assortments of twisted pipes or tensioned flowerpots in their textbook. By covering the same technical concepts and merely swapping out the types of examples used ensures that no additional class time is "sacrificed" for culturally relevant pedagogy, which seeks to ensure students' academic success and helps them to embraces the development of cultural competence. The hope is that students will build an intuition and appreciation for forces that will serve them regardless of their major. Chen and Wodin-Schwartz (2019) describe how to tackle contextualization in increasing levels of effort and impact, ranging from simple in-class explanations (e.g., couple moments are experienced each time you use a grocery store cart) to socio-political projects where students consider the social impacts of their engineering design (i.e., cable placement for tensioning an electricity-generating balloon turbine in a fictional village). These contextualizations within course curricula are simple examples of culturally relevant pedagogy in action where everyday examples are a starting point to relate to students' lived experiences.

Author DAC also has applied Statics concepts to the socio-political realm. In a one-week module on centroids and center of mass, students learn about gerrymandering in the United States and how the electoral college balances the vote between land mass and population mass (Chen and Przestrzelski 2019). Students conduct an analysis on their hometown district, practicing concepts of resultant forces, center of mass, and engineering modeling (i.e., making assumptions and simplifications) on a real scenario, to evaluate if their district has been gerrymandered. In this module, students use Statics concepts as a proxy for measuring socio-political disparities and critique the U.S. political system that allows for and encourages decision-makers to skew the distribution of citizen votes for their own benefit. This standalone module is an example of culturally responsive pedagogy, where students are encouraged to challenge the status quo of U.S. politics and investigate whether current socio-political issues might be affecting their own communities.

### Thermodynamics

In their second year, many students are living off campus for the first time and have just started paying their own electric bill, though few have ever actually read their bills. Author GDH introduces a connection between course content and lived experience in a Thermodynamics course by bringing in his own energy bill and asking students to read the bill and identify areas they find interesting. This generates a discussion about the surprisingly complex ways in which electric charges are assessed, which then creates an opportunity to discuss the real costs of generating energy. This discussion leads students to realize that the vapor power cycle they have been discussing in class is just one small part of the energy ecosystem.

This exercise helps students connect their learning to practical examples of relevance in their lives. It also opens the door for socio-political conversations in an engineering context. For example, energy pricing is often done on a progressive model (i.e., the less energy you use, the lower your per-unit rate becomes). At face value, this may seem like a perfectly reasonable system, but when digging deeper, interesting inequalities begin to emerge. For example, the progressive model for energy pricing uses a per household model. Students are asked to think about the consequences for multigenerational households and which of these consequences might be detrimental to marginalized communities. Students come to realize that these households pay higher per-unit costs for energy even though their per-individual energy usage is lower. This, in turn, provides an entry point to discuss the housing crisis in California and reflect on the way in which this energy policy actually incentivizes having fewer people living in each residence.

### Circuits

In Electrical Circuits, author SML has incorporated several modules that relate to social responsibility. These include a discussion of conflict minerals, a trip to an electronics recycling center, and a session with a social entrepreneur (Lord, Przestrzelski, and Reddy 2018, 2019). The first module, "Conflict Minerals," is introduced after students learn about capacitors. During a class discussion, students are presented with a definition of conflict minerals within the context of the Democratic Republic of the Congo (DRC) and how these minerals are used to produce the capacitors in smart phones. Students are then challenged to consider ways to minimize the use of conflict minerals as engineers. Ideas included recycling, reuse, optimizing designs, synthetic production, and researching alternative materials.

There are several elements of CRP incorporated into this module, primarily in connecting to students' lived experiences. In discussing the consequences of minerals being mined in a conflict area, SML used the context of a Sony Playstation video game that caused the price of one mineral (Tantalum) to spike in 2000. This had problematic consequences for people, particularly child laborers in the DRC. This example also made it possible to connect the class discussion to the recently released movie "Black Panther" as the fictional Wakanda is in a similar geographic area as the DRC. This gave an opportunity to contrast how the people in Wakanda used and benefited from their mineral wealth with the situation in the DRC. Lastly, the module aimed to help students develop their socio-political consciousness by raising awareness of how the technical items students will one day be asked to design are connected to global issues.

## Radical Change: Social Justice in Engineering

Students' responses in focus groups, surveys, and interviews to these interventions suggested we were onto something that resonated with them. More importantly, it gave us confidence that we – engineering faculty – can (and should!) actually talk about socio-political context in our classrooms. We have now implemented two brand new required courses in our curriculum that challenge students to go much further. As a Catholic liberal arts institution, we have a substantial set of core requirements that all students must meet for graduation. This includes a requirement that all students must complete two courses that focus on issues of diversity, inclusion, and social justice (DISJ). Students had typically taken courses outside of engineering to satisfy this requirement and often complained that they were irrelevant. Recognizing that connecting DISJ issues to engineering is challenging for students and faculty, we saw this as an opportunity to create new courses that integrated these themes directly within engineering courses to help students see the relevance of DISJ to their education and work as engineers. As we, as engineering faculty, do the hard work of connecting DISJ concepts to engineering, we model this for students and send a message that this is important for engineering, not something to be outsourced to another department and ignored. We created an introductory course for second and third semester students, User-Centered Design, and an upper-division course for juniors and seniors, Engineering and Social Justice.

### User-Centered Design Course

On its own, User-Centered Design (UCD) is already an uncommon course for most engineering curricula, though its popularity has grown in recent years. User-centered design differs from traditional engineering design in that students are asked to consider the users of their products and how their design might impact various users differently. With the DISJ lens on top of this, the course we offer specifically focuses on users who are often marginalized by society, let alone excluded in engineering (e.g., women, people of color, people with disabilities, people who experience poverty and homelessness, and so on). As our student body is primarily White and wealthy, we do our best to move students out of their comfort zones to develop empathy and understanding for users who they see as "not like them"– one explicit goal of the UCD design process.

*UCD Case Studies Activity*
In addition to framing engineering design in a context where the decision makers must turn to the lived realities of stakeholders, our course also aims to help students develop a critical consciousness regarding the objectivity of technology and its impacts on society. In an activity conducted over two consecutive class periods (Mejia et al. 2018), students choose from a list of articles about different types of technologies, such as an overpass bridge that stops buses from accessing a wealthy neighborhood (Campanella 2017), a GPS app which unintentionally promotes residential discrimination and segregation (Keyes 2012), how air conditioning temperature models have excluded women from the workplace (Bichell 2015), and how facial and voice recognition systems can perpetuate systemic racism and sexism if left unchecked (Breland 2017). Students are asked to discern not only the key points the author raises and the information and evidence (or lack thereof) used to support their claims, but also critically consider the stance of the author and how this might have influenced their reporting.

After evaluating the article as a whole, students are asked to analyze the technology itself and create a short presentation to summarize their findings to their classmates. Their presentations address what the nature of the controversy is concerning the technology, what the positive and negative lasting implications of the technology are, who the technology is designed for, who it disadvantages, who the designers and decision-makers were, and lastly, to evaluate whether or not the innovation aligns with the definitions of social justice previously discussed in class (Mejia et al. 2018).

Students discover in these UCD case studies that technology is designed by humans, and when diverse users and designers are not consulted through testing or included in engineering decision-making, technology can perpetuate deficit-based stereotypes and further exacerbate disparities. This realization leads into a discussion of social constructions, and students are eased into concepts such as social identity theory, intersectionality, and privilege. (Instructor reflections on the challenges of this work have been discussed in detail elsewhere (Mejia et al. 2018; Chen, Mejia, and Breslin 2019)). One modification made to the course over the years has been walking back the upfront sociotechnical nature of the course content and instead couching the sociotechnical objectives within a technical framework. For instance, recent iterations of the course use the engineering design cycle as its foundation even while we teach user-centered design, integrate participatory design, and encourage design for user empowerment (Mejia et al. 2018; Ladner 2015). In the end we hope students see that in order to design successful solutions for all of society, all of society must be represented within the design process.

*Vocation in Engineering (Values) Activity*
Following course content about the privilege that can come with social identity, and its difference from personal identity, we conduct an activity in class using "value cards" to help students reflect on their personal values (Chen et al. 2019). Our goal is to help students think early and deeply about how the ways they may want to live as a person may differ from how they are leading their lives as engineers. In this activity, students (and faculty instructors as well) are asked to sort a deck of 83 cards with values on them (e.g., "authority", "fitness", "wealth", etc.) into three piles based on how important that value is to them. This exercise aims to directly address our program outcome to help students develop a critical awareness of their personal attitudes, behaviors and values and the ways in which these align with their professional aspirations by having them examine the boundary between their engineering identity and their personal identity (Mejia, Chen, and Chapman 2020). This activity implicitly asks students to think critically about the culture of engineering and whether this culture continues to engage them with the social issues that may have drawn them to engi-

neering originally (Cech 2014).

There are several elements of culturally responsive and culturally sustaining pedagogy infused throughout this class. By using a lens of user-centered design that specifically examines the impact of technologies on marginalized groups, this course pushes students to challenge the status quo of engineering. Students learn the value of listening to users and the importance of context through the UCD case studies activity; engineering solutions are more successful when the designers choose to first understand the issue at hand and who is impacted, rather than dive head-first into problem-solving.

The final course project brings together the topics of social constructions, privilege and disparities, and user-centered design in an example of CRP. Previous course projects have included need-based community engagement work with local schools, nearby foodbanks, a blind community center, and an organization for children with autism, among others. Most recently, students have designed solar water heater prototypes that integrate with a mobile shower through the work of a homelessness advocacy group (Chen, Chapman, and Mejia 2020). In all of these projects, students must reconcile these topics in their own views and treatment of their design project's user, build empathy for users whose experiences with technology and injustice are different from their own, and set aside their nascent engineering hubris to recognize that engineering alone cannot solve sociotechnical problems. This introductory course aims to help students build socio-political consciousness around their engineering education and sets them up for the upper-division course, Engineering and Social Justice, where a deeper and more personal dive is taken.

## Engineering and Social Justice Course

This course supports students' understanding of engineering in relation to social justice, and seeks to help students develop critical consciousness by infusing critical literacies throughout class activities. For this course, critical literacies are incorporated as a way to help students read texts in an active and reflective manner that can lead to better understanding power, and analyze inequality and injustice in engineering contexts (Freire and Macedo 1987). The course uses a dialogical approach to create an environment where dialogue is central to the learning experience (Freire 1970; Luke 2012). The dialogical approach is the basis for critical pedagogy and provides the means to engage in culturally responsive education by equipping students with the tools to read the world around them, give them voice, and engage in emancipatory practices (Freire and Macedo 1987). Author JAM developed this course to analyze the world of engineering as portrayed in media, literature, advertisements, and other functional texts (Shor and Freire 1987). To that end, writing is a central component of the course and the vehicle through which students explore issues of diversity, inclusion, and social justice.

Students discuss many different ways in which engineering can impact people and perpetuate injustice. These include displacing communities, facilitating imperialism (through militarism and designing for technology), disrupting ecosystems, and discriminating against certain groups, among others (Leydens and Lucena 2017). One of the activities includes asking students to write a proposal that provides a pathway toward design for social justice. Students are required to critically analyze every aspect of their capstone design project (e.g., problem definition, researching the problem, developing solutions, selecting potential solutions, prototyping and testing), and propose how the project can become a design for social justice using Leydens and Lucena's criteria for social justice (Leydens and Lucena 2017). The criteria for social justice are meant to serve as a guide to recognize and map human and non-human, technical and non-technical factors involved in the design of engineering solutions. Moreover, the activity provides the elements for the students to critique and challenge, or even transform, dominant ideologies in engineering.

One of the key learning outcomes of this activity is to develop an understanding of the environmental, social, cultural, and economic context in which engineering is practiced. This holistic contextual understanding is crucial for students to examine the success or failure of all engineering projects, regardless of scale. Students are expected to demonstrate their understanding of the context of their project by using the knowledge gained throughout the semester. Students used their reading materials, discussions, and research notes to assist them in writing this proposal. These critical components of the course are designed to provide students with space where they can learn about engineering decision-making processes (i.e., helping students succeed academically), explore different perspectives and recognize traditional knowledge as a form of engineering knowledge construction (i.e., developing cultural competence), and to instill in them a socio-political consciousness (i.e., challenge the status quo and analyze how engineering impacts marginalized communities) (Ladson-Billings 1995).

This course is designed to help students develop a critical consciousness (Freire 1970) and become aware of the oppressive systems and institutions that engineering has contributed to creating. It also serves the purpose of learning from the past to create transformative change in the field. While not all students may reach a level of critical consciousness, most students linger in a state of critical transitivity (Freire 1970) where they engage in an in-depth analysis of some of the problematic aspects of engineering but their capacity to dialogue is still fragile. One example is the oversimplification of complex issues in engineering as a response to the strongly-held idea that engineering is technology-driven. Nonetheless, reaching this stage is extremely important for students because their progression toward critical consciousness can continue to improve if these conversations continue to exist in other engineering courses. Reaching critical consciousness is not dependent on one single course, but on the institutional context and how students are guided throughout their undergraduate years to grapple with both the positive and negative aspects of engineering culture and practice.

## Reflections on Radical Change

Implementing these courses has not been without its challenges. We have faced substantial resistance to the idea that the engineering curriculum should include elements of social justice or diversity. Disappointingly the courses have been undervalued by engineering faculty outside our department more than by students or those at other institutions. Detractors assert and insist that the courses are not sufficiently “rigorous”, a term Riley convincingly argues is primarily aimed at “disciplining, demarcating boundaries, and demonstrating White male heterosexual privilege” (p. 1, Riley 2017). Nonetheless, the courses are now an integral and required part of our curriculum.

One of the biggest challenges we have faced is attempting to change the culture of engineering as mostly pre-tenure faculty. This work is controversial and invites criticism, adding a layer of complexity on top of an already stressful tenure process. Moreover, there are challenges attached to the fact that these efforts are primarily spearheaded by women and faculty of color who often “have to endure the sometimes hidden, sometimes overt climate of exclusionary culture” (p. 12, Chen, Mejia, and Breslin 2019) of engineering.

Our one tenured author, SML, bravely shares the following reflection on her own work in this area:

> *It has taken me years to figure out how to incorporate some social relevance into Electrical Circuits. What helped me was having the opportunity to partner with an anthropologist. It was challenging to determine how to present the conflict in the Democratic Republic of the Congo (DRC) with enough depth for students to appreciate the complexity without overwhelming them or trivializing people’s struggles. I did not feel comfortable doing this on my own. Several students commented that they appreciated that we did not make this a guilt trip. This was important for getting them to engage rather than tune out. I have been asked several times how I found the time in the course for this. Most of the students in my section of the circuits class were mechanical engineering (ME) majors. Honestly, I feel that the four days spent on this module and two other related ones on social responsibility are more likely to be impactful than much of the detailed, abstract and mathematical content for these ME students. One ME and one EE student got summer jobs because of this experience at the Electronics Recycling Center on campus which we had visited as a class activity, which was an unexpected benefit.*

> *Nationally, response from colleagues within the ASEE Electrical and Computer Engineering (ECE) Division has been interesting. When I wrote a paper describing this work entitled "Teaching Social Responsibility in a Circuits Class," (Lord, Przestrzelski, and Reddy 2019), reviewers wanted more explanation of why social responsibility was important. After the talk, a White man came up and said that this was the best presentation he had ever seen at a conference. He said that I had really made him think. Then he said that when he read the title, he didn't think the talk would be good or interesting. Three other White men then echoed these thoughts. This made me wonder why the ECE community has trouble with the term "social responsibility" particularly given the ABET criteria which include helping students develop "an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts" (ABET 2020). I believe these responses were genuine but I also wondered about a culture where people consider it appropriate to say they thought your work was going to be bad. I also wondered about the gender dynamics of this interaction. I have also had several women engineering educators reach out to me to ask me to speak about this work or share information so they could incorporate it in their classes and I know at least one has done so.*

More broadly, this institutional change would not have been possible without several key factors. First, there is a committed group of faculty at our institution who believe in the importance of this work. Fostering a group of allies has made it possible to shift the curriculum and begin to shift the culture. We meet regularly as a group both to strategize future initiatives as well as debrief setbacks. Second, we have a dean and associate dean who are supportive of these efforts and one of us, SML, is the chair of our department. Without support from leadership, this effort would have stalled many times. Our School of Engineering received a National Science Foundation (NSF) Revolutionizing Engineering Departments (RED) grant which has supported some of these efforts and brought institutional and national recognition. Finally, we are at a Catholic institution that values, promotes, and holds issues of diversity, social justice, and inclusion as part of its mission and vision. By aligning with our university mission, we have garnered support from others across campus including our Office for Community Engagement, Tribal Liaison, and Center for Educational Excellence. We recognize this as a unique set of circumstances and realize that others may not be in a similar position. That being said this work is a marathon, not a sprint. While the last five years have seen rapid changes at our institution (Hoople et al. 2018; Hoople et al. 2019, 2020; Nelson et al. 2020), faculty have worked for decades to lay the groundwork for these changes. We are actively collecting data on how students have responded to these interventions and plan to present these results in future articles. We are also developing plans to partner with other institutions to see how we can share these types of curricular change more broadly across engineering education.

## Conclusions

We hope that the tides are turning towards more inclusive engineering pedagogy. Recent failures by large engineering companies clearly highlight the need for change. To name just a few, recall Uber's unacceptable corporate culture (Kosoff 2018); Boeing's unethical decision to financially benefit from neglecting important safety features (Tabuchi and Gelles 2019); Google's 2015 image-recognition system that labeled Black people as "gorillas" (Vincent 2018), Amazon's 2018 system that confused congressmen, predominantly those of color, with criminal mugshots; and a report that darker-skinned individuals are more likely to be hit by self-driving cars than their lighter skinned peers (Samuel 2019). These examples reveal the need for more diversity, inclusion, and consideration for justice in engineering. We assert that this goes beyond allowing more women and people of color into the "elite" space of engineering. Rather it involves changing the culture of engineering education including our pedagogical approaches to create a new culture that includes and welcomes a diverse set of viewpoints. To be successful in solving these problems, engineering students must learn to understand the complex cultures, ways of living, and ecosystems in which engineered systems exist (Baillie and Catalano 2009). The entire engineering community must be willing to call out problems such as racism and sexism (Simmons and Lord 2019).

With this article, we have highlighted a set of pedagogies that faculty can learn from to help change engineering culture. We reviewed a small fraction of this work and provided examples of how it can be applied within an engineering context. While we understand how hard this approach is to adopt whole cloth, we hope to encourage engineering educators to look outside of engineering for inspiration. Engineering is about solving problems *for people*, that means we need our graduates to understand more than the narrow technical aspects of a problem. Engineers cannot continue to be oblivious and claim that engineering occurs in a socio-political vacuum if we hope to have the positive social impact that is championed in both corporate and university mission statements.

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