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Introducing Engineering through the Sociotechnical Histories of Everyday Technologies

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I. The Changing Landscape of Engineering Education

In 2009, the Engineering Accreditation Commission of ABET Inc. turned its attention to the growing number of requests from constituent groups urging the expansion of the criteria required of degree-granting engineering programs in the US. These criteria, generally known as Engineering Criteria 2000, or EC2000, had been developed over the course of a decade, and at the time of its debut in 1996, EC2000 was considered revolutionary in its shifting of focus away from what is taught towards what is learned. In the intervening period, however, difficulties particularly associated with its eleven technical and professional outcomes—appearing as Criterion 3(a)-(k), Student Outcomes—bubbled to the surface.

Along with the results of a study commissioned by ABET in 2002 and completed in 2006, ongoing ABET reviews and independent studies of engineering curricula across the country brought into stark relief the struggles many programs faced in interpreting and/or satisfying Criterion 3 requirements [1]–[3]. In comparing responses from 2004 graduates against their 1994 counterparts, the study completed in 2006 uncovered one surprising result: 2004 graduates reported a “chillier diversity climate than that cited by their predecessors” [1, p. 6]. The study report speculated that several factors could be at play, including “differences in the gender and racial/ethnic mix in 1994 and 2004, graduates’ awareness of diversity issues, and/or their willingness to discuss and challenge prejudice or discrimination.” Nevertheless, continued the report, “[t]he evidence provides no guidance in the way of an explanation”[1, p. 6]. Though it’s not clear what, if any, work was done to unpack these or other potential explanations, it is evident that diversity, along with equity and inclusion, are no longer peripheral to ABET accreditation criteria.

Following a series of discussions taking place in 2013-2015, Criterion 3(a)-(k) were replaced with seven numerically-listed targets, Criterion 3(1)-(7), that have been in effect since 2019 and are complemented by revisions to Criterion 5, Curriculum. Of Criterion 5(a)-(e), the call for an educational component that “promotes diversity, equity, and inclusion awareness” in item 5(c) replaces an earlier proposal from 2015 which called, instead, for a component “that includes humanities and social sciences….” This, despite contrary statements from constituents such as the National Society of Professional Engineers (NSPE), which called for inclusion in Criterion 5 of a “specific reference to ‘humanities and social sciences.’” In a position statement last revised January 2023, NSPE explains that “Both the humanities and the social sciences are of critical importance to engineers of all disciplines, both as learned professionals and as practitioners”[4, p. 4]. As the curricular changes introduced in the present paper will suggest, training in the humanities and social sciences is how the recently-introduced definitions of “diversity,” “equity,” and “inclusion” can be successfully translated into pedagogical practice.

In light of developments in society at large, including most notably the murder of George Floyd in May 2020, ABET issued two letters in June 2020 condemning systemic racism and committing itself to leading the way in accountability in STEM education [5], [6]. Less than a year later, engineering Deans of the Big Ten+ Universities urged ABET in March 2021 to include diversity, equity, and inclusion (DEI) in the general criteria for accreditation. DEI, they argued, needs to be embedded within the engineering curriculum in order to create an inclusive culture and community within engineering colleges themselves [7]. Though initially approved by the ABET Engineering Area Delegation in October 2021, revisions approved a year later have cut important passages from the proposed definitions of "inclusion" and "equity," leaving "diversity" unchanged.

Initially, "inclusion" was defined as "the intentional, proactive, and continuing efforts and practices in which all members respect, support, and value others. *An inclusive environment provides equitable access to opportunities and resources, empowers everyone to participate equally, and offers respect in words and actions for all*"(emphasis added). A year later, however, the second sentence was redacted. Similar changes were made for "equity," originally defined as: "the fair treatment, access, opportunity, and advancement for all people, achieved by intentional focus on their disparate needs, conditions, and abilities. *Achieving equity requires understanding of historical and systemic patterns of disparity to address and eliminate barriers and remove participation gaps as part of a comprehensive strategy to achieve equitable outcomes and social justice*"(emphasis added). Here, too, the second sentence was redacted. As this paper will show, the content of the two redacted sentences italicized above is precisely what is demanded by any genuine efforts to introduce meaningful change to engineering pedagogy. Put simply, if the engineer of tomorrow is to be adept at navigating the complexity of 21st-century life, engineering curricula would do well to incorporate—rather than shy away from—the necessary historical and sociological training that places engineering in context.

II. Institutional Context and Motivation

In August 2022, a recent graduate of an interdisciplinary doctoral program in Science, Technology, and Society (STS) joined forces with the Chair of the Engineering Department at Loyola University Maryland (LUM) to radically transform the university's introductory engineering course. The former contributor arrived at the project having spent several years experimenting in the classroom with various pedagogical strategies intended to historicize for engineering students the political, social, and economic context in which they (and those who came before them) have lived, learned, and worked. That the complementary interests and skills of a recent STS PhD and a seasoned Electrical Engineer would converge on the same problem (i.e., How to place engineering in context?) and at the same moment in time (i.e., mid-2022) may be fortuitous. More likely, though, it is a product of the times in which we live.

The late 2010s and early 2020s have been an unusually tumultuous period around the world. While hundreds of thousands of Americans began losing their lives to covid-19, hundreds of thousands more risked infection by pouring into the streets all over the world in solidarity with black, indigenous, and people of color communities. Universities across the country began demanding "Diversity Statements" from prospective faculty, announced the creation of new DEI offices, and raced to display what seemed to many boilerplate "Black Lives Matter" statements. Some of the nation's oldest and wealthiest colleges doubled-down on recent efforts to disclose their financial, cultural, and political ties to the institution of slavery and to the devastation of American Indian tribes [8], [9].

By any measure, higher education today is currently grappling with the necessary growing pains accompanying the sorts of hard conversations that are starting to become normalized across academia. In some ways, LUM is no exception to the rule. It is, after all, a private, liberal arts university with small class sizes, high tuition, and a pristine campus that sits, as so many American colleges do, a short distance from the neglected neighborhoods home to the city's marginalized communities of color [10]. In light of such challenges, the emphasis on DEI in engineering programs has been steadily increasing at the authors' institution as it has with many other institutions across the US.

As a Jesuit Catholic university committed to "the ideals of liberal education and the development of the whole person,"[11] LUM operates primarily as an undergraduate institution with considerable liberal arts requirements. Students who pursue LUM's ABET-accredited bachelor's of science in engineering must select one of four concentrations in electrical, computer, mechanical, or materials engineering. At the same time, all students are required to complete courses in the natural sciences and mathematics, as well as in the humanities and social sciences wherein reading, writing, and critical thinking skills are heavily emphasized [12]. The LUM Core Values Statement "calls upon the curriculum to prepare students to dedicate themselves to diversity that values the richness of human society as a divine gift and to pursue justice by making an action-oriented response to the needs of the world.[12]" Given the uniquely holistic aims of the LUM community, the practice of *reflection* laying at the core of the Jesuit tradition invigorates all corners of the university to respond to nationwide calls for social, political, and economic justice.

At present, LUM's strategic plan places a strong emphasis on DEI through the recruitment of students and faculty from underrepresented groups and the creation of more inclusive classrooms and curricula. The university's stated diversity aims include "awareness of the structural sources, consequences, and responsibilities of privilege [11]" and "awareness of the global context of citizenship and an informed sensitivity to the experiences of peoples outside of the United States.[11]" Of particular relevance here is the ongoing revision being made to the university's diversity course requirement. As it now stands, students are required to take one diversity-designated core, major, or elective course for graduation. Such courses must entail a substantial focus on global awareness, justice awareness, and/or domestic diversity awareness. While students have traditionally enrolled in discrete diversity courses housed mainly in the humanities and social sciences, revisions currently underway will soon hold each department responsible for its own diversity content. Changes in the engineering curriculum thus come as part of a wider rethinking of pedagogical practice across the university.

Along with the imminent implementation of new ABET criterion, the combination of the latest revision to the university's strategic plan, the growing number of students majoring in STEM, the Engineering Department's desire to better integrate itself within LUM's liberal arts core, and a nationwide reckoning of systemic biases that shape our historical present—all of these together have served as an important impetus for radically rethinking LUM's engineering curriculum, starting with EG 101: Introduction to Engineering.

III. EG 101: Then and Now

Prior to the revision of EG 101, few engineering courses touched on the entire social, political, and environmental impact of engineering and its technological products. This resulted in the need to better connect students' engineering know-how with the critical thinking skills they learned in their humanities and social science courses. As a course open to engineering and non-engineering majors alike and as one of only two engineering courses that count towards students' core curriculum requirements, EG 101 was seen as a promising mechanism for better-integrating engineering with the liberal arts while recruiting and retaining a wider array of students than ever before. The course described here is thus the first step in creating content that places engineering in its historical, philosophical, and sociological context in ways that are accessible and inviting to all LUM students.

Previous iterations of the course functioned primarily as an introduction to the technical content in electrical, computer, materials, and mechanical engineering. The course employed a two-part model where the semester-long course was split in half; one half of the semester was dedicated to introducing students to the preliminary topics in materials and mechanical engineering, while the second half of the semester was dedicated to preliminary topics in electrical and computer engineering. Two different instructors were employed; where one instructor lead the mechanical and materials portion of the course, and another instructor lead the electrical and computer engineering portion. Typical course topics in the materials and mechanical engineering portion of the course included: metals and atoms, hardness testing, microstructures and properties, Hooke's Law, and the design of trusses. Typical course topics in the electrical and computer engineering portion included Ohm's Law, the resistor color code, equivalent resistance, power, digital logic, ASCII, and concepts regarding computer programming like basic variables and conditional statements. In addition to these technical topics, professional orientation to engineering was addressed with lectures on career opportunities, resume development, etc.

Centered on preliminary topics in computer, electrical, materials, and mechanical engineering, past versions of EG 101 functioned as a tasting buffet of courses to come but without going far enough into any area to add depth to learning. Furthermore, the assumption that career possibilities in each discipline were fixed in advance was seen to fit uncomfortably with the shifting reality of engineering practice—in which a given set of skills does not necessarily translate into a given set of careers. Additionally, the first year is always a crucial time for retention in engineering programs and a great opportunity to spur interest in interdisciplinary minors like Environmental Studies as well as Technology and Entrepreneurship.

To encourage students to view engineering as a means for translating or realizing one's personal values in the form of tangible, real-world effects, the first-named author proposed a syllabus that opened with the following line: *"What does it mean to be an engineer?"* Students would be explicitly encouraged, both in the new syllabus and during class, to find their own answers to this question in light of an eclectic mix of readings, videos, case studies, lectures by guest speakers, self-reflection exercises, and other activities intended to bring engineering's past, present, and future to life. Kicking off the course was an overview of US engineering history from the 19th century on through the present day. After learning about the roots of the "pure" science vs. "applied" technology dichotomy, students then learned how engineers redefined themselves as professionals while negotiating a balance between mathematical theory, on the one hand, and practical problem-solving, on the other. Following this historical introduction, students then worked their way through four modules examining key moments in the social and technical development of key technologies known to affect and be affected by everyday life in America, namely: (1) cell phones, (2) cars/automobiles, (3) wind turbines, and (4) smart doorbells.

With each module presented as case study, students practiced thinking critically about such questions as: How did these technologies arise? What problems were they designed to address? Which materials have gone into fabricating and powering these technologies? How are these materials sourced? Why does the supply chain matter? What happens when these technologies start nearing the end of their lifecycle? What hopes or concerns did they raise for society, and how might engineers respond? In the process of examining the social and technical arc of each technology "from cradle to grave," so to speak, students were introduced to computer, electrical, mechanical, and materials engineering—LUM's four engineering concentrations. To help ground these subfields in LUM's engineering curriculum, each module included a 10-minute video created by engineering faculty that provided a fundamental technical overview of the technology in question while also emphasizing specific engineering courses students could take to learn more about technical and theoretical features in greater depth.

Key rationale for examining the historical, political, and technical development of everyday technologies were to (1) cultivate student interest and situate learning about engineering disciplines, (2) create a sense of belonging in the department and university, and (3) demonstrate the impact of engineering on everyday life. Student interest, sense of belonging, and engineering utility are three vital factors in student retention. For instance, Jones, et al in [13, p. 1352] states that student "belonging was the strongest positive predictor of intentions to stay in engineering major, followed by engineering program expectancy and engineering utility." and " engineering belonging showed the highest correlation with intention to major, which reinforces the importance of curricular structures that enable students to experience a sense of community and connection." While the National Academy of Engineering in [14] states the system to educate engineers should include several elements including "the economic, political, ethical, and social constraints as boundary conditions that define the possible range of solutions for engineering problems and demand the interaction of engineers with the public.[14, p. 18]" The National Academy also stated that surveys of pre-college students consistently demonstrate an interest in careers where "helping-others" is a key aspect and that it would be "particularly helpful if the engineering community could successfully communicate the social context of engineering—how engineering has made enormous contributions to our quality of life—and the social responsibilities of engineers beyond just taking care to exercise their skills responsibly. [14, p. 27]"

For the second-named author, it was hoped that, by moving to a new format, the following would occur: (1) Students would develop a better sense of how interdisciplinary modern technology developments are and how electrical, computer, materials, and mechanical engineers work together to realize these technologies; (2) see how each concentration contributes to devices/technologies that may be perceived as being primarily one discipline (i.e., cell phones are completely the work of computer engineers); and (3) pique student interest in engineering via technologies, they use and interact with. As students were to discover over the course of the semester, engineering's many subfields have supplied humanity with powerful tools for effecting real, concrete changes in the world—for better and for worse. Indeed, by highlighting 1950s critiques of engineers as corporate middle-managers [15] as well as Vietnam-era critiques of the military-industrial complex, the course did not shy away from using historical examples to teach professional and ethical shortcomings and the relationship of these shortcomings to a misguided belief in a value-free or "apolitical" engineering practice [16]–[18]. These and other topics were also addressed through individual and group activities.

Students were eased into critical thinking activities through two initial self-reflection exercises. Regardless of their intended or potential career goals, students were asked in the first exercise to reflect upon what they perceived to be the dominant images of engineering today [19] and to share their views of what, in their view, life as an engineer might allow them to accomplish that other profession might not. This was followed by a second exercise introducing students to classical philosophy's is-ought distinction, with students asked to reflect on a morally-challenging experience from their own lives in which "what is" did not align with what they believed "ought" to be. In another assignment, students completed one-on-one interviews with individuals old enough to recall the impact on local communities of the deindustrialization, or outsourcing of manufacturing jobs, that took place in the 1980s. For the midterm, students were tasked with researching the events leading up to, during, and after the Volkswagen emissions scandal, an episode in recent history during which Volkswagen executives scapegoated German engineers. Later, following a lecture discussing differences between Japanese and American corporate culture, students were asked to identify an American company with high CEO-to-worker pay ratios and discuss factors they believed contributed to this pay gap. As part of the module on smart doorbells, in which students learned about facial recognition technologies, and deep learning neural networks, students examined the tension between civil rights and liberties, on the one hand, and government surveillance, on the other.

Other activities included the "Partners in Ethnography" assignment, which accompanied a lecture comparing the styles of Danish vs. American and German wind turbine developers. Pairs of students were asked to silently, simultaneously, and independently conduct 30-minute observations at two sites of their choosing, swap fieldnotes with each other after the fact, and submit separate essays noting the similarities and differences between their two perspectives. Other group work included PowerPoint presentations on how the benefits of the transition away from fossil fuels may or may not benefit historically-neglected constituencies, such as the Navajo in Southwest US. For final projects, students researched and presented posters in teams discussing technological problems or possibilities they believed to be deserving of more attention from the engineering community. These and other projects were coupled with mandatory yet ungraded weekly online forums to which students were asked to exercise their critical thinking skills by posting responses to the prompts provided and to each other. In-class activities included conversationally-delivered lectures, discussions with guest speakers, and screening of films such as *Who Killed the Electric Car?* and *Revenge of the Electric Car*.

Through such activities, the course specifically aimed to meet the following ABET student outcomes: 3.4) the 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; 3.5) the ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives; and 3.7) the ability to acquire and apply new knowledge as needed, using appropriate learning strategies. With these revisions in place, then, the course became an entirely new endeavor for the Department of Engineering, and for LUM more broadly, in that it asked students to reflect on the processes that shaped how engineering has been defined and put to use over time, as well as how the engineers of today impact society and the environment.

IV. Initial Findings

Before the end of the semester, students were asked to submit a "Final Self-Reflection," in which they looked back through their essays, group projects, and weekly forum posts. These final reflections offer powerful testimony to the transformative ability to integrate historical and sociological content into engineering curricula. The following excerpts are presented here in anonymized form with permission from eight students:

Having entered college already committed to one engineering subfield, Student 1 wrote:	"I never thought about the other forms of engineering that would interest me as much as they have while in this class. …I never imagined how closely they are all interconnected. … The main reason is because we talked about the history of multiple different fields that all tend to intersect. … Looking towards the future,…the engineer that I want to be [is] one that is in it for helping others and having a sense of appreciation for the field, something that has become more valuable to me after taking this class."
Student 2 was inspired by the course to major in engineering:	"At the beginning of the semester, I wasn't really looking into engineering as a possible career path for me. I took this class as a way to learn more about it but now I think engineering might be something I want to pursue. This class has taught me that there's so much more to engineering than just crunching numbers all day. Engineers work for the betterment of society. … Wherever I end up in the future, I want to be able to help people. This is part of the reason why I am now considering a career in engineering."
Student 3 commented on specific research-heavy activities (of the kind described in ABET 3.7) that piqued their interest:	"Projects such as the Volkswagen Emissions Scandal Essay, as well as the forum on facial recognition technology opened my eyes to the tangible consequences of irresponsible engineering. In summary, I learned that engineering cannot be considered an 'amoral' profession. … I'm not a huge fan of writing papers, but I really enjoyed the research portion of the Volkswagen Emissions Scandal essay. I think this project marked a turning point where I realized that the decisions of engineers can have an enormous impact on the people around them. … The essay on Biases in [Facial Recognition] Technology was another project which led me to reflect on the ethical responsibilities of engineers. …it teaches an important lesson in how a limited perspective can lead to unequitable technology."
Student 4's reflection testifies to the viability of weaving critical thinking skills directly into engineering coursework:	"This class was unlike any other class, whether in college or high school, I have ever taken before. Prior to taking this class, when I saw EG or ENG followed by numbers on my schedule I expected to do critical thinking, but in a math, or science sense. This class shifted that expectation drastically. Each time I entered this class, especially later in the semester, I was challenged with new ideas of what it means to be an engineer. Less of a thought of getting told there is a problem and solving it but rather identifying the problems yourself and working to make the world a better place in terms of one's own moral code. … I think engineering is now more of a toolset rather than something you learn. It's a toolset to solve problems of oneself and others."

Student 5 valued seeing engineering as a means to effect positive, large-scale change:	“Going into the course, I did not fully understand just how many people engineers are able to impact, and the many ways in which they can. Learning about just how important engineers are made me want to be an engineer even more than I did before. … The possibility that I could do some real, tangible good in the world is an exciting prospect.”
Student 6 noted the enormity of the impact that engineers have on society & valued inspiring guest speakers	“Before taking this course, I had no clue what I was getting into. I knew engineering was an applied science and mathematics and design were an aspect, but I was not sure at what scale engineers were working and their input into society. … My initial plan with a Mechanical Engineering degree was to work and gain experience. … After taking this course I found there are so many other routes to take, I feel as if I have a sense of what that can look like. … I had no idea…startups were a career option for engineers. I figured most engineers entered a company.”
Student 7 transitioned from viewing group work as a burden to recognizing peers as sources of strength:	“I had always known from the beginning that working in engineering would undoubtedly require collaborating with peers. This idea never appealed to me. I had the impression that I could handle everything on my own, from assignments to projects to assessments. I’ve learned throughout the [semester] through a series of assignments how [u]tilizing the expertise of your peers can help you complete your assignment faster and more effectively than you might have anticipated. … As for my current outlook on the field of Engineering, I’m as optimistic as ever.”
Like their peers, Student 8 indicated the value of guest speakers:	“Currently, I still don’t know what job I want out of college. I never would’ve thought about creating a new company given the right circumstance. Because of the guest speakers, the thought of creating a company interests me. … This course showed me the problems engineers face and they are not only hard when it comes to the physics and calculus needed. But also the ethical dilemmas behind each piece of technology.”

V. Discussion and Next Steps

By using methods from social sciences and the humanities that allow students to place themselves and engineering in context, such as one-on-one interviews, historical reviews, and ethnography, a driving motivation for the course redesign was to have students walk away at the end of the semester better able to articulate what kind of future they wished to see and how engineering could help them and their communities bring that vision to life. Just as students learned to situate technologies in their historical and political context, so too do they contextualize their own worldviews and predilections. Firsthand observations of students, together with the quotes provided above, strongly indicate considerable strides were made in this direction. Similarly, the emphasis on critical thinking skills as a means to better integrate EG 101 with the liberal arts core suggests we are on the right track in taking a first step towards revising the curriculum as a whole. In the near future, the successes of this experimental redesign will be used to inform department-wide strategies for not only meeting but exceeding the university’s latest diversity goals, which holds all departments individually responsible for offering their own diversity-designated courses. The work that lies ahead involves strategizing just how higher-level engineering courses will make room for activities that place engineering in its social and political context.

Starting with the prompt, “What does it mean to be an engineer?,” it was decided that the new version of EG 101 would be structured around four everyday technologies that were familiar to students and faculty alike. While students were expected to have directly or indirectly experienced the four technologies for themselves, faculty were expected to be able to create short introductory videos conveying engineering know-how that would be linked to specific, upper-level engineering courses. Whether other technologies than the four initially selected would in some way improve the course remains an open question. Another limitation is the selection of activities. All individual assignments, forum prompts, and group projects were chosen on the basis of prior success with student engagement in a notably different learning environment. Since A large part of what made this redesign so experimental was due to uncertainty as to whether the same activities originally developed and tested at a large, secular, rural, land-grant polytechnic institution would be similarly successful in the context of a small, Jesuit, urban, private liberal arts institution.

At the same time, with the course only recently introduced, it’s not yet clear what sort of impact this experiment has had in attracting and attaining a wider array of students than previously. However, as the passage shown above from Student 2 suggests, at least one student entered the course uncertain of their interest in engineering; by the start of the following semester, this student had declared their major in engineering. As for student retention, only time will tell whether the broad social and political framing provided by the course can be translated (albeit in abbreviated, possibly new ways) into the more technically-challenging, upper-level courses. The redesigned EG 101 may not suffice to guarantee retention over all four years, but if changes yet to be made to upper-level courses can redeploy similar critical-thinking activities, students may well be encouraged to persevere by continuing to see themselves as powerful agents for change in a world riddled with ethical challenges and possibilities.

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