2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #37292

Receiving curricular messages: Engineering students' understandings of valued practices in their field

Shannon M. Clancy, University of Michigan

Shannon M. Clancy (she/they) is a Ph.D. candidate in Mechanical Engineering at the University of Michigan. She earned a B.S. in Mechanical Engineering from the University of Maryland, Baltimore County (UMBC) and an M.S. in Mechanical Engineering from the University of Michigan. Her current research focuses on idea development and ideation tools, divergent thinking, and engineering curricular practices and culture. Her research interests include front-end design practices, sociotechnical knowledge and skills, and queer student experiences in engineering. Their work is motivated by their passion for and experiences with inclusive teaching and holistic mentorship of students, seeking to reimagine what an engineer looks like, does, and who they are, especially for queer folks, women, and people of color, through empowerment, collaboration, and co-development for a more equitable world. Shannon is also a Senior Graduate Facilitator and Lab Manager with the Center for Socially Engaged Design.

Berenice Alejandra Cabrera, University of Michigan

Berenice Alex Cabrera (she/her) is a Ph.D. student in Higher Education at the Marsal School of Education at the University of Michigan. She earned a B.A. in Biology and Latinx Studies and a minor in Chemistry from San Francisco State University (SFSU). She also earned a Master's in Cell and Molecular Biology from SFSU and a Master's in Higher Education from the University of Michigan. Alex taught biology at community colleges in California before attending the University of Michigan where her research interests pivoted to engineering education. Her current research interests focus on examining the messaging undergraduate engineering students receive with respect to the type of work that is valued in engineering. Her research is centered around the goal of making engineering curriculum more socioculturally relevant and the field more inclusive of women and students of color.

Ms. Sarah Jane (SJ) Bork, University of Michigan

Sarah Jane (SJ) received her B.S. and M.S. in Electrical and Computer Engineering from the Ohio State University in 2017, and her M.S. in Engineering Education Research from the University of Michigan in 2020. As a doctoral candidate in Engineering Education Research at the University of Michigan, Ann Arbor, Sarah is studying the mental health experiences of engineering graduate students.

Kayleigh Merz, University of Michigan

Kayleigh Merz (she/her) is a recent master's graduate in Higher Education from the University of Michigan. She earned a B.S. in Cognitive Science from the University of Michigan, and associate degrees in Mathematics, Physics and Engineering, and Computer Science from Lansing Community College. Her research interests include the impacts of culture on students and their sense of belonging, graduate education, and the faculty experience. This work is motivated by her experience and training in student affairs and her enthusiasm for student development and inclusive environments. She is hoping to continue her work and research in an engineering education Ph.D. program in the coming cycle.

Dr. Erika Mosyjowski, University of Michigan

Erika A. Mosyjowski (she/her/hers) is the Research and Faculty Engagement Manager in the Center for Socially Engaged Design at the University of Michigan. She has a B.A. in Psychology and Sociology from Case Western Reserve University and a M.A. and Ph.D. in Higher Education from the University of Michigan.

Dr. Shanna R. Daly, University of Michigan

Shanna Daly is an Associate Professor in Mechanical Engineering at the University of Michigan. She has a B.E. in Chemical Engineering from the University of Dayton and a Ph.D. in Engineering Education from Purdue University.

Dr. Lisa R. Lattuca, University of Michigan

Lisa Lattuca, Professor of Higher Education and member of the Core Faculty in the Engineering Education Research Program at the University of Michigan. She studies curriculum, teaching, and learning in college and university settings, particularly how fac

Dr. Joi-lynn Mondisa, University of Michigan

Joi Mondisa is an Assistant Professor in the Department of Industrial and Operations Engineering and an Engineering Education Faculty Member at the University of Michiganâ€"Ann Arbor. Dr. Mondisa holds a PhD in Engineering Education, an MS in Industrial

Receiving curricular messages: Engineering students' understandings of valued practices in their field

Abstract

This research paper examines the curricular messages perceived by students about what practices are valued and central to engineering work. Emphasis on certain practices, and de-emphasis on others, can impact if students see themselves as engineers and their interests in engineering. In this study, we compared the experiences of two 3rd-year Industrial Engineering students and two 3rd-year Mechanical Engineering students through semi-structured interviews. We analyzed these data guided by Holland and colleagues' figured worlds framework to build an understanding of the engineering practices and skills students perceived as important in their courses, what values, activities, and interests were encouraged and discouraged by their instructors and peers, and how these practices and skills aligned or misaligned with student career and engineering interests. Our findings showed that teamwork, problem-solving, technical communication, and using foundational technical knowledge were perceived by students as emphasized most in their classes. Students discussed how these practices and skills built the foundation to do their engineering work but were at times dissatisfied with the lack of social considerations around stakeholders, sustainability, and contextual aspects of their work. Students further described career interests to solve complex, societal issues. This paper has implications for incorporating sociotechnical practices and broader careers interest into engineering curriculum.

Keywords: figured worlds; engineering curriculum; engineering culture; engineering practices; alignment

1. Introduction

Engineering curriculum frequently focuses on technical, analytical, and decision making knowledge and skills, evident by the common focus of courses on math and physics principles [1]–[3]. Course problem sets and projects routinely focus on determining variables and solving equations where there is one "right" answer [4]. However, engineering work is inherently both technical and social [5], [6]. To address major problems of today's world, engineering students need to develop contextual and cultural competencies, ethical responsibility, and social engagement knowledge and skills, as well as the ability to work across disciplinary boundaries [7]–[10]. Engagement in these skills, which we collectively call "comprehensive engineering knowledge and skills", are necessary to develop impactful, innovative, and successful engineering solutions [9]–[11].

In addition to preparing engineering students to successfully address modern engineering problems, the inclusion of comprehensive engineering skills in the curriculum has implications for students' engagement and persistence in the field. Students' engagement in their field as well as their plans to pursue an engineering career or engineering graduate education is determined in part by an alignment between their personal and professional interests and values in engineering and curricular messages about what engineering practice includes. For some students, the potential to leverage engineering for social good is a key motivation for pursuing work in the field [12], [13]. Further, research suggests that socially-oriented engineering work attracts a more diverse group of students [14]; minoritized students disproportionately pursue engineering to create solutions to make a better world within their communities, create innovative solutions that align with their values and interests, improve people's lives, and address large scale global problems such as climate change, global health issues, and various types of resource access [15]–[18]. For students of any identity who are motivated by the social impacts of engineering work, a disconnect between their interests and the often narrowly technical focus of engineering curriculum has the potential to negatively impact their sense of fit and desire to persist in engineering work [19]–[21]. Thus, in this research we conducted in-depth interviews to explore what messages students received about what practices were central to their engineering disciplines and how these emphasized practices impacted their engineering engagement and pursuits. Understanding these alignments and misalignments can inform curricular revisions in both what is taught and how the practices of engineering are discussed.

2. Background

2.1 Engineering Practices and Culture

While the engineering profession presents itself as a field that is objective, neutral, and depoliticized, i.e., purely "technical" space, where political and cultural concerns can— and *should* —be removed [22], engineering is inherently a social discipline that is impacted by and impacts people [22]–[25]. Beliefs that engineering work is purely technical can lead students to view societal concerns as distractions from engineering work and become disinterested in examining the social implications of their projects [26]–[28].

We collectively call the skills necessary to integrate social and contextual considerations into technical engineering work as "comprehensive engineering knowledge and skills." These practices include, but are not limited to, collaboration, creativity, cultural and contextual awareness (e.g., social, economic, political, cultural, environmental), ethical responsibility, and interdisciplinary competency. Comprehensive engineering knowledge and skills are key to successful engineering practice as emphasized in numerous engineering reports and scholarly works [1], [10], [29]. The Accreditation Board for Engineering and Technology (ABET) includes many comprehensive skills to their program accreditation criteria, such as social responsibility and consideration of global, economic, and cultural factors [23], [30]. There have also been some pushes from industry professionals who want to see engineering graduates better prepared for the workforce by demonstrating an ability to contextualize engineering work in coordination with technical skills and knowledge [23], [31].

While comprehensive skills are important to engineering work, their inclusion in curricula is lacking [1], [29], [32], [33]. Even when a non-technical skill is noted as important, such as on course syllabi, this skill may not receive the same focus as the technical skills in practice and assessment within the course. For example, a study of teaching creativity in engineering found many engineering courses that had fostering creativity as a learning outcome included assessments of convergent thinking skills like evaluation and analytic thinking but little to no assessment of the divergent skills necessary for creativity like openness to uncertainty and exploring ideas and problems [34]. This is a potential signal to students that if a skill is not assessed, it is not important and valued in the classroom, as students are motivated to learn and engage in knowledge and skills from an alignment of learning goals, activities, and assessment [35]–[37]. Without alignment and consistent opportunities to engage and gain feedback on comprehensive skills and knowledge in a course, there could be limitations in potential learning, feedback, and improvement of comprehensive knowledge skills for both students and instructors.

If students were to gain necessary comprehensive engineering knowledge and skills, they may gain them in the form of collaboration, ethical responsibility and interdisciplinary competence through out of class experiences, such as co-curricular organizations like project teams, professional engineering societies, or identity based organizations, research, study abroad, and internships [12], [23], [38]. However, the extent to which various comprehensive knowledge and skills are explicitly emphasized and effective in fostering such skills in those experiences vary [39], [40], especially in regards to cultural and contextual awareness in engineering work [23], [26].

While these co-curricular experiences can be helpful and beneficial to engineers' learning [41], the implications of these types of opportunities being mostly outside of the classroom are potentially detrimental. For example, putting the responsibility on students to build these skills outside of required engineering courses may lead to perceptions that these skills are secondary and non-essential [28], [40]. Moreover, not all students may have opportunities or access to participate in out of class experiences due to socioeconomic disparities or may have a variety of negative experiences related to their race, ethnicity, and gender in some co-curricular experiences that lack an inclusive or equitable culture [42]–[44]. Therefore, students' development of necessary engineering skills is best enabled through continued practice in regular coursework as curricular activities and learning outcomes in courses communicate what is important for engineering students to learn as perceived by students and faculty [38].

Students motivated to pursue engineering with goals to solve complex societal problems may experience a sense of misalignment in their engineering courses that lack a focus on sociotechnical knowledge and skills [20], [45]–[47], and unsurprisingly, this misalignment of values and interests in engineering can lead to a lack of sense of belonging for these students [46], [48]. The underemphasis or omission in the engineering curriculum of sociotechnical concepts developed by diverse groups may dissuade students from studying or continuing in engineering [12], [49]. This is due, in part, to the content that is required in engineering which has historically been constructed by dominant culture [50], [51] with a narrow technical focus separate from sociocultural knowledge and skills. In particular, students of minoritized and marginalized backgrounds, such as but not limited to, women, people of color, disabled people, and/or queer and trans people, are less likely to pursue a degree in engineering, or more likely to leave engineering during their education or career [52]–[54].

These barriers to diverse participation have become such a prominent issue that it threatens the nation's global competitiveness [55]. Studies have demonstrated that diverse groups tend to be more creative and innovative in their problem-solving strategies - a trend that the field of engineering strives for [46], [56]. As a result, it is imperative that engineering education examine and restructure the delivery of content and incorporate more sociocultural content in engineering curriculum to attract and retain more talented diverse students [57] and prepare engineers to solve the world's complex problems.

2.2 Figured Worlds Theoretical Framework

Our work is guided by the figured worlds theoretical framework by Holland, Lachicotte, Skinner, and Cain [58]. Figured worlds are "socially and culturally constructed realms of interpretation in which particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued over others" [58]. The figured worlds framework draws on activity theory [59] to emphasize the dialectical nature of people and their environments in which individuals actions are shaped by the cultural meanings and values within a given environment and in turn shape those cultural meanings through their actions. Further, Holland and colleagues emphasize how particular actions and the meanings ascribed to them differ in the extent to which they are recognized as meaningful or valued in a given world and that individuals occupy different positions within (or are excluded entirely from) them [58]. The extent to which one's activities are widely recognized as meaningful or valuable by others in a given environment is determined in part by the extent to which these align with the dominant forms of practice in that space. Individuals' actions may in turn serve to reinforce or gradually redefine the cultural meanings and values central to that environment, or be excluded from that space.

For the purpose of the present study, this framework brings a focus on understanding (students' perceptions of) the dominant forms of practice that constitute what it means to "do engineering" in the context of core engineering courses in two disciplines. We examine the extent to which the dominant forms of practice within these disciplines align or misalign with individuals' own values and interests related to the practice of engineering, and the potential consequences for students of this alignment or misalignment. The aspects of engineering practice emphasized in students' core courses are likely to inform students' understandings of what it means to do engineering. We know the undergraduate curriculum serves as a primary vehicle for transmitting messages about important disciplinary competencies, interests, and values of a given discipline [60], [61]. If, for example, an instructor routinely asks students to consider human impacts of solutions to engineering problems during the course, students may be more inclined to weigh such factors in their own work, seeing them as valued elements of engineering and an available way to be recognized as an engineer within that cultural context. Over time, then, individuals' personal definitions of engineering work may come to more closely align with their engineering community's dominant forms of engineering work.

While students' experiences in core courses are likely a powerful influence on their engineering interests and values, the aspects of engineering practice emphasized in these courses may or may not fully align with students' personally held values and preferred practice of engineering, as these are likely shaped by a myriad of unique experiences students bring with them into their undergraduate studies. The figured worlds framework suggests that when students' personal values or preferred practice of engineering do not align with the dominant forms of practice emphasized in their courses, these students may struggle to see themselves as an engineer as defined in that context, may be less likely to be recognized as doing engineering by their peers and faculty, or otherwise feel a sense of disconnect or exclusion from engineering.

We utilize the figured worlds framework in our study of four upper-level engineering students in mechanical and industrial engineering disciplines. The framework was used to orient our attentions to what they perceive to be the valued practices of their fields based on their engineering course experiences, how these align with the students' own interests and values, and how this relationship, if at all, has shaped students' experiences in the field and their intentions to pursue an engineering career or graduate study.

3. Methods

The data for this paper comes from a larger study of two engineering departments at a large Midwestern research institution. The larger study examines curricular messaging about the nature of engineering practice in two engineering fields and how these curricular emphases align with students' engineering interests and values and the ways this alignment may shape their career intentions after graduation. Data for that study includes interviews with 65 first- and third-year mechanical engineering (ME) and industrial engineering (IE) students and follow-up interviews one year later recruiting the same students. Additional study data include observations of multiple core courses in each discipline, interviews with faculty who teach core courses in ME and IE, and a survey sent to all undergraduate students in both disciplines. In this paper, we draw on data from interviews with four advanced undergraduate students (two in each discipline) to begin to characterize the aspects of engineering they perceive to be emphasized in their core courses and the variation in how, if at all, students' own engineering interests and career aspirations align with these course emphases.

3.1 Researcher Positionalities

There were many members on this research team. The team included a mechanical engineering Ph.D. student (SMC), an engineering education research Ph.D. student with a background in electrical engineering and experiences teaching IE courses (SJB), a higher education master's student with experiences teaching STEM courses (BAC), a higher education master's student who left engineering (KM), a staff researcher with a background in higher education and studying engineering students' experiences (EM), a mechanical engineering tenured faculty member (SD), an industrial engineering faculty member undergoing the tenure review process during the study (JLM), and a tenured professor in the school of education with a faculty appointment in integrative systems and design in the college of engineering (LL).

One motivation for this study was to investigate what students learn about engineering practices in their engineering coursework, and how messaging from the curriculum about what are important engineering practices relates to students' sense of fit and intentions to persist in engineering. On the other hand, this study was motivated by our lived experiences as both learners and educators within engineering and engineering education. We have experiences revamping and developing courses to better accommodate a diverse range of students and their interests for being in engineering. However, we know that not all of the engineering faculty have embraced this change, and that some students have felt marginalized and unwelcomed in engineering as a result of their courses. We therefore hope that this study can collect evidence to show how curricular messaging in engineering can change to be better aligned with students' values and interests and how intentional curriculum design can change the culture in engineering.

With these motivations, experiences, and prior literature in mind, we came to this study expecting to find some students' interests in engineering not aligned with the messaging they receive in their coursework. Because of the technical focus of many engineering courses, we expected some students to seek out skills and knowledge beyond what courses emphasized, while other students would have a strong sense of alignment with their engineering curriculum.

3.2 Research questions

The aim of this study was to understand what curricular messaging engineering students received about engineering practice within their disciplines, how students felt about those messages, and how those messages shaped how students thought about their future careers. To do so, we sought to explore the following guiding research questions:

1. What do students learn about the nature of the work of their engineering discipline during their undergraduate education?
2. How does what students learn about the nature of the work of their engineering discipline align with students' own engineering values and interests?
3. How does this alignment between what students learn about the nature of the work of their engineering discipline and their personal values and interests relate to their intentions to persist in their major and/or pursue graduate study or an engineering career?

3.3 Participants

This paper presents preliminary findings of interview data collected from four participants at one large, Midwestern university in the United States from two engineering disciplines, mechanical engineering and industrial engineering. The participants included four upper-class undergraduate students: one Asian female mechanical engineering (ME) third year (Participant A), one White male mechanical engineering third year (Participant B), one mixed South Asian and White industrial engineering (IE) recent graduate (Participant C), and one white male industrial engineering third-year (Participant D). The four student interviews analyzed in the present paper were selected from the larger dataset based on a review by multiple co-authors because of the richness of their narratives and range of engineering practices and experiences they discussed.

Students were recruited into the larger study via email using listservs generated from registrar data to target first- and third-year engineering students in IE and ME. We aimed to recruit participants across a range of identities and prior experiences, sharing our recruitment message widely with all first- and third-year students who expressed an interest in declaring or who had formally declared ME or IE as a major. Included in the study solicitation was a pre-screening survey, asking potential participants to confirm their eligibility for the study as well as collect background information. Gender, pronouns, and race/ethnicity were the only demographic information collected and were self-described. Participant C (recent IE graduate) was included in our study due to having three years of IE coursework at the time of recruitment as he had changed majors in his second year. The team was not aware of his very recent graduation until the interview, and decided to proceed to capture his experiences.

3.4 Data Collection

Data were collected through semi-structured interviews, guided by an interview protocol we developed and piloted based on our research objectives, relevant literature, and study team members' prior experiences [62]. After several iterations of protocol development within the team, the protocol was piloted by the study team with eight third- and fourth-year engineering students (three IE, four ME, and one other). As a result of piloting, we revised the protocol based on how well questions facilitated interviewees in discussing the topics we were trying to probe. During the design, piloting, and iterations of the protocol, we took intentional care and review of the protocol to create clear and consistent open-ended questions in a way that allowed students the opportunity to share and describe their personal perspectives and experiences without leading them to a particular response [63] and compare engineering disciplines.

The final interview protocol had six main sections: (1) warm-up and background experiences, (2) educational messaging on nature of engineering work, (3) students' values and interests in engineering, (4) students' choices and intentions to persist, (5) final reflection, and (6) end/sign off. Interviews were conducted via Zoom and audio recorded. Interviews ranged in length from 30-to-90 minutes.

The four graduate students (SMC, SJB, BAC, KM) were responsible for conducting the interviews. Their positionalities, identities, and lived-experiences influenced how they interacted with the participants. Each interviewer was first interviewed by another member of the team to better understand the personal experiences and biases that were elicited by the interview protocol. This provided insight into the experiences the interviewer would be likely to try and confirm in the data collection process, and could therefore be mindful of during interviews to avoid questions and engagement that made the interviewee feel uncomfortable or inauthentic. Furthermore, as students themselves, the graduate students were able to relate to students' experiences in college that helped build trust and dialogue during the interviews.

3.5 Data analysis

Recordings of the interviews were transcribed, de-identified, and reviewed for accuracy. The interview transcripts were inductively analyzed [62], [64] under three threads: (1) educational messaging from students' engineering courses and program (e.g., what engineering is, what distinguishes their engineering discipline from others, etc.), (2) student values and interests in engineering (e.g., what they liked most/least about courses, sense of belonging, etc.), and (3) student career interests, choices, and relationships between their courses or major and their career interests.

Leveraging the theoretical framework, engineering practices literature, and guiding research questions, the first author (SMC) read each transcript in full multiple times, and wrote initial thoughts to situate herself within each participant's data. Treating every participant as a case, she pulled out all passages potentially relevant to this study's research questions from the transcript to holistically review the participants' experiences, and sorted each question and response for every participant to identify all instances of data by research question. She wrote summary statements to make meaning from the participant's responses and gather evidence for each research question. An example of the data and summary statement from Participant A is provided below.

> Interviewer: "*Expanding on that last question about, are there certain things that an ME engineer, distinguishes them from other engineers? What have you learned are the skills or knowledge that you would need to be considered a good ME engineer?*"
>
> Participant A: *"I think that really depends on what field you go into, but basically, any particular skills that would make you a good mechanical engineer? I think [a] skill [is] to understand a little bit of every other field. As a mechanical engineer, you would definitely be working with many other fields. On your team, there's probably going to be*

> *an electrical engineer, not one, but a group of them, and also aerospace, or others. I think a good skill to have is to understand a little bit of everything. The classes that we take now agree with this, because we take a little bit of electrical courses. We also take material science courses. It helps us because we're so broad, and for all engineering fields in general, we're constantly working with engineers from other fields. I think it's really important, maybe more than any other fields. It's almost like a bridge. We have to understand a little bit of every other field, so we can communicate with them. I think that's a really important skill to have."*
>
> Summary statement: *ME is a broad discipline where a good professional ME needs to have skills from a variety of engineering fields, which is reflected in the breadth of courses taken, such as circuits and material science, necessary to communicate across engineering disciplines.*

The first author then wrote summaries of each participant based on these statements and how each participant discussed and thought about each research thread, frequently going back to the data. The first author discussed each participant's summary with a co-author (EM) to gather feedback and iterate for clarity, meaning, and accuracy of participants' responses. The first author was then asked to have another author (BAC) review this process in a close manner.

The second author (BAC) read each transcript, reviewed the supporting data and summary statement for each research thread developed by the first author (SMC), and reviewed the summary for each participant. In particular, the second author (BAC) was encouraged to find new themes and note any differences of interpretation, framing, and perspectives of each participant's experiences when reading the transcripts and data analysis. For example, the second author (BAC) identified an additional practice of technical communication for Participant A as emphasized in her courses. Both co-authors then met to discuss all discrepancies and agreement for each participant summary. They frequently returned to the data collected and transcripts during this meeting to ensure participants' language and experiences were accurately represented, where the co-authors iteratively revised the interpretation of the data and added themes and clarity to the summaries until full agreement was achieved to finalize the summaries.

Both first and second authors were very familiar with the data as they both conducted interviews and were familiar with the literature and engineering practices for the larger study. They had extensive training and experience piloting the interviews, data analysis training, and reconciling processes for the larger study, preparing them both to be uniquely situated and informed to conduct analysis of this work. They made intentional designs in data collection and analysis to center the participants' narratives. For example, by having both authors review the data and develop themes, they were able to check their assumptions made on the data and discuss how underlying assumptions could lead to inference from personal experiences as opposed to what was shared by participants.

4. Findings

In this section, we describe *what curricular messages* about engineering practice each of the four participants described, *how those messages aligned or misaligned* with their own interests and values, and *how the alignment or misalignment impacted their future engineering plans*.

4.1 Participant A - 3rd Year ME

Curricular Messages:

Participant A reported technical knowledge and analysis and building skills were the most emphasized skills and knowledge in her required courses due to the types of class topics and how classes build on each other's content. She said:

I feel like a lot of the classes that I've taken are related to [calculations and analysis], because they also build on each other. You have to take [Solid Mechanics], and then you can take…[Mechanical Behavior of Materials]... It's the specific ideas, just more and more in depth.

Participant A perceived a variety of skills and knowledge were included in mechanical engineering courses, describing that most technical courses focused on calculations, analysis, and understanding of foundational knowledge, while design courses focused on application of skills, teamwork, and creating and building in hands-on ways. She noted that there were only three design courses for students to learn these non-technical skills.

She viewed ME as a broad discipline, and felt that the courses emphasized a breadth of content from a variety of engineering areas:

"I think a.good skill to have is to understand a little bit of everything. The classes that we take now agree with this… we're constantly working with engineers from other fields…We have to understand a little bit of every other field, so we can communicate with them."

Curricular alignment with student interests

Participant A described feeling very interested in the technical content of materials science and manufacturing more broadly and felt a strong sense of alignment with the content of her courses in this area. She was able to pursue a research experience with the instructor of her materials science professor focused on these topics to pursue these interests further. She also stated she desired more opportunities in courses to apply her knowledge and skills and better understand engineering choices. She expressed expectations for more hands-on experiences throughout her courses, not just in the design courses:

"I think I expected more hands-on experiences, things like the [design courses]. I actually don't have as many classes about that as I thought I would. I really thought I would learn a lot more about things like, how different types of nuts and bolts work, and why we have to use a washer sometimes, and things like that. Actual applications, if you actually want to build something in your garage. I thought I would learn a lot more about that."

She explained how she had to find these experiences outside of classes through project teams and internships, where she realized her interest in manufacturing and production.

Alignment or Misalignment to Future Plans:

Overall, Participant A described an interest in the aspects of engineering practice emphasized in her coursework and an intention to persist in the field of engineering. Participant A discussed her plans to pursue a one year master's program before getting a job in manufacturing at an aerospace company. She planned to apply content from one of her design and manufacturing courses in her future career. Participant A also discussed how she did not think some of her courses were relevant to what she wanted to do:

At one point I took [Programming]...Basic coding skills, definitely, but data structure, maybe not so much. I don't know if I'm going to need a lot of the knowledge that I'm learning from system dynamics and control. Maybe, because for the production line, if you have robotic arms, that's definitely very related to that. I feel like that's not what I envision myself doing in the future, designing those things.

<u>4.2 Participant B - 3rd Year ME</u>

Curricular Messages:

Similar to Participant A, Participant B described a noticeable difference in practices emphasized in his technical courses and practices emphasized in his project-based courses. He said the most emphasized skills and knowledge in ME courses were technical modeling and analysis, teamwork, and communication. He discussed the dissonance between these two types of courses and desired more teamwork and communication within his technical courses. He also felt that some courses named practices that were important, but then did not follow through on emphasizing those skills in the course. For example:

Always at the beginning of the year in the first lecture, the professor makes one note or slide saying "Remember the ethics in engineering and do the right thing for the world." And then throughout the vast majority of courses that I have been in, it is never brought up again in any of the examples they use. The examples that they use are frequently purely technical..."

This participant highlighted a key difference in his courses. While ethics as a practice in engineering is espoused by his professors and field, he stated a lack of integration of social considerations into his coursework. He further discussed that these classes could incorporate the core technical *and* social aspects: *"whether that's looking at different stakeholder views or looking at environmental impacts from an interpersonal human standpoint, rather than a tech standpoint…That's something that is not highlighted in other engineering or even ME courses."* He indicated that many examples in his classes looked at simplified, out of context problems and solutions.

This participant also said that a good professional mechanical engineer needs a baseline of technical skills and understanding, dedication to learn and work, and technical communication. He learned this from his Design and Manufacturing II course. *"The techcomm paper… feels like a due diligence report a little bit where you need to show that you've put in the engineering work where it doesn't exactly matter if the end result is correct, but just that you legitimately tried and you took all of the things that you were taught in a short amount of time and applied them to the best of your ability…"*. Participant B, further, characterized mechanical engineers as a more "*generalist*" engineer, where other engineering fields are a bit more specialized.

Curricular alignment with student interests

Participant B expressed a strong sense of misalignment with the ME field and his ME courses. He named multiple examples of topics he wished were integrated into courses to push students to think about issues like sustainability goals, how people are impacted by engineering solutions, and opportunities to situate work within local community contexts . He felt frustrated and exasperated by a lack of emphasis on these aspects in his classes. He discussed how this lack of consideration in engineering courses was rooted in capitalism and positivism within the field and industry funded by company and university interests, valuing the technical skills and content over others.

Participant B described how he felt most of his ME courses didn't address what he was most interested in and valued about engineering work, explaining he felt his "*courses line up between 25-35% with what I'm most interested in*." Even with the strong misalignment, Participant B named teamwork, communication, and complex problem solving of real-world systems as engineering work aligned with his interests, evident to some extent in his design courses. He discussed how engineering provides students with the complex tools to design complex systems, but it's also within a capitalist system to make profit.

Participant B also sensed that his priorities and goals were not well-aligned with those of his peers given his interest in sustainability and equity:

"I'm here because I want to do renewable energy or make change in the world. Other people are here because engineering pays well or they're really interested in space and want to design spaceships. I feel a larger societal pressure to use the advantages that I've had just handed to me to try and make the world more equitable…"

He perceived that the dominant mindsets of his professors were rooted in positivist beliefs about engineering. He expressed concerns about this emphasis, citing the harm engineering has the potential to do where "*...science is separate from society…*", a separation he described as conflicting with his values. Further, he described "*...in the overarching theme of ME, of meritocracy, of work your butt off, get paid well, don't worry about the systems you're designing for the government…In that sort of system, I don't feel like I fit with that* [ME] *community…*" with the ethical implications of that type of work conflicting with his motivations and values.

While he expressed a strong sense of misalignment with the majority of his core courses, Participant B did find a sense of belonging and a connection and alignment with his values and interests in two ME electives: Racial Justice in Engineering and Sustainable Engineering Design. He expressed that these courses highlighted both the social and technical aspects of engineering work. The ME students and professors in these courses focused on impact, sustainability, and equity, as well as gave him the language and tools to more deeply understand the misalignment he was experiencing and critique his required mechanical engineering courses and the field.

Alignment or Misalignment to Future Plans:
Participant B expressed substantial frustration with his engineering training and planned to leverage his ME degree in a more broadly focused future career in renewable energy. He explained that his ultimate career goal was to create a non-profit:

"...I work on a team with other engineers, but also with a lot of not engineers, some language based people, some culture based people, some society and community based people to develop

renewable engineering solutions…highly affected either by the cost of energy in their area, the lack of environmental protection in their area, the environmental resources that they have…to create equitable distribution of renewable energy technologies to communities that don't traditionally have access [and the community takes ownership of the project]."

He explained that he was most interested in working in a US context "*because we have inequities and inequalities here just as much as other places around the world.*" He intended to first work on renewable energy technologies at a smaller company for a few years before transitioning to less technical work focused on "*...the human impacts of renewable energy or other highly societal engineering design*".

Though Participant B had a desire to work in the renewable energy sector prior to starting university and he felt a majority of his courses had little influence on his career goals, he did feel his engineering training helped him develop technical understanding and technical communication skills that would enable him to discuss renewable energy concepts in understandable ways, so communities have the resources to understand and maintain the technologies. With regard to his required courses, he believed that technical communication and how to "*move through the web*" by critically thinking and solving problems would be most beneficial to his career plans, while content and skills from his elective courses on racial justice in engineering and sustainable technology design were the most relevant for his future career. In addition, he joined a project team and pursued an internship about wind turbine technologies after he learned about these opportunities from his introduction to engineering course.

4.3 Participant C - Recent IE Grad

Curricular Messages:

Participant C reported that the most emphasized knowledge and skills in his IE courses related to technical knowledge and skills, such as optimization, business and finance, statistics/stochastic processes, simulation, machine learning, coding, modeling, and analytic skills, as well as how to look at problems:

"I can't walk into a restaurant without thinking about how is this line, like a queue, how can we make this better? My brain is basically geared towards looking at problems and trying to make things better…finding inefficiencies and solving them."

He explained many of his courses had application-based problems and utilized different skills and approaches. He perceived optimization and computational methods to be the topics emphasized most in the curriculum. He noted that while the curriculum included content on cultural engineering and human factors, these were less emphasized. Additionally, in his senior design course, he described having the opportunity to develop professional engineering skills such as working on a team, holding people accountable, navigating conflicts and issues of unequal contribution, and thinking critically.

Based on his experiences in engineering courses in other disciplines, Participant C perceived many engineering fields place an emphasis on problem definition and analysis, figuring out technical methods to solve problems, and proposing solutions. However, compared to other fields like ME or aerospace, he felt IE placed a greater emphasis on broader skills beyond physical solutions. He described the field as"*...more on the delivery of the product, where the product is in our long term view, resources used to make the product…We think to make things efficient.*"

Curricular alignment with student interests
Participant C expressed strong alignment between IE course content and his own engineering values and interests. He described how he had enjoyed a majority of his classes due to a variety of applications and topics "*...on the cutting edge of IE*", and how it was interesting to approach a problem with different methods and skills from different classes. Additionally, Participant C described how he enjoyed his Global Cultural Systems Engineering course, which integrated philosophy and social aspects into engineering:

"*Understanding cultural values and stuff like that makes so much sense…when you're coming up with an engineering approach in another country, you need to think about these things because it might not work the way it works in the U.S.*"

He never felt pressured to do a certain type of IE work; he perceived he had the flexibility to learn a bit of everything IE had to offer and dove deeper into his interests. He did wish, however, that more coding and machine learning courses were offered in the curriculum due to their relevancy in IE and industry.

Participant C mostly expressed alignment of values and interests in engineering with his professors and peers. He described how professors *"...love to hear what we are passionate about, especially in office hours, a lot of just small talk [we] have with instructors,*" especially about his experiences with healthcare research. He discussed how he aligned with some peers and instructors through "*helping people or doing something you care about,*" especially in his healthcare research experience. He did point out, however, a more common value of engineering:

"I definitely think a lot more engineers would say they value solving problems and I think that's not a coincidence, that's what engineers do…I think that's something that would come up a lot more than potentially other people. And the instructors, [problem solving is] what they've dedicated their life to doing. Someone that has a PhD in IE is probably pretty dang good at solving problems…"

Alignment or Misalignment to Future Plans:
Participant C expressed an interest in applying his IE training within the healthcare field, doing work related to healthcare policy and consulting. In the short term he planned to go into consulting, "*...striking a lot of deals with healthcare companies…being able to pitch IE solutions…to say, okay, now, we're going to use this type of optimization model to improve your efficiency by X amount and we can predict it this way because we have information on how your company functions…*" He was considering the possibility of eventually pursuing a policy or public health master's degree, and did not rule out a PhD in IE so he could start his own healthcare consulting firm using IE methods and solutions.

He explained that his interest in healthcare was shaped by his undergraduate experiences working in a research lab with the local hospital trying to improve the system during the

COVID-19 pandemic and how that impact had "*fortified my values for helping people…when you can see the change you're making…*" He anticipated drawing on much of what he learned in his coursework in this future work, including operational mathematics, optimization skills, improvement of processes, and technical communication. His IE courses shaped his desire to use "*data driven solutions,*" mathematical models, and tools, planning to use every skill he learned at some point in his career.

4.4 Participant D - 3rd Year IE

Curricular Messages:

Participant D described data analysis and use of statistics in optimization techniques as the most emphasized skills and knowledge in his IE courses, noting instruction on these topics across multiple courses that built upon one another. He saw his courses in quality engineering principles and optimization and computational methods as foundational and applicable to many different disciplines; in particular, he viewed optimization as typical IE work "*...combin*[es] *all the stats we've learned, the optimization methods…basically every core course is incorporated in there*." He also named an emphasis on technical communication, stating *"You have to be able to be concise, keeping to a certain word limit, use these terms, make sure anyone who's reading it can understand."* He explained that his technical courses focused on one area of knowledge, such as business and finance, work organization, and operations management, while design courses are the application of knowledge from multiple technical courses. He mentioned there hasn't *"felt like a huge teamwork component in most of [his] classes, there's been* [individual] *projects."*

He contrasted IE with other engineering disciplines given the field's focus on *"trying to improve processes, instead of the actual physical components of a system."* Further he explained, *"it seems like most of industrial engineering's very intangible, and we're not really building, we're just doing analysis, or trying to figure out ways to improve a process through analysis…"*. To be a good professional industrial engineer, he learned that having comprehensive knowledge, clear and understandable technical communication, and problem-solving skills to *"identify a problem...define, measure, analyze, interpret and conclude…"* are necessary to be successful. He explained that the intangible nature of IE did not make him *"always feel like an engineer."*

Curricular alignment with student interests

Participant D expressed strong misalignment between his IE degree and his personal interests and motivation for pursuing the degree. He felt the *"*[IE] *department doesn't exactly do a great job of marketing what it does."* He felt his courses focused too heavily on statistics and manufacturing and not enough on business and organizational philosophy, which he found frustrating because prior to declaring a major*"...everyone was telling* [him] *it's the business degree for engineers."* He chose IE after switching from aerospace engineering as "*[it] was the closest to a business major or an economic major, so* [he] *just thought 'Perfect, this is what I should be doing'*." Ultimately, he felt disappointed with the focus of his IE degree, explaining it did not challenge him to think broadly beyond the technical. He wanted different perspectives, and ways of thinking. He expressed a desire for a greater focus on business principles and their application within engineering.

Participant D's frustration with the focus of his coursework ultimately led him to regret his decision to pursue a degree in engineering. He felt another major that focused more on both human behavior and mathematics would have been a better fit, but was reluctant to switch out of IE into a business or economics degree because he perceived such degrees to be less marketable for jobs and due to the high value of his university's engineering degree. *"I regretted doing engineering, and it was too late to switch into business..."* Despite this regret, he was committed to completing his degree as he wanted "*...to go work, and…have the degree*".

Alignment or Misalignment to Future Plans:
Ultimately, Participant D felt few of his IE courses were relevant to his future career and solidified his decision to pursue a career outside of engineering. He planned to pursue strategy consulting and investment banking after he completes his education. While Participant D described dissatisfaction with most of his courses, he felt they provided a lens to "*...understand what* [he's] *interested in personally at a deeper level*", equipping him with skills and knowledge about how organizations and systems are run, how to structure a facility, and find most optimal solutions. Though he did not intend to work in an engineering field, he did feel that finishing his technically focused engineering degree demonstrated his capabilities and that he could apply his engineering skills and problem solving methodologies in the finance field. He also anticipated that his coding training would open more doors for him professionally.

5. Discussion

5.1 Student perceptions of curricular emphases

This paper presents an in-depth look into two mechanical engineering and two industrial engineering students' perceptions of curricular emphases in their engineering disciplines, how these curricular emphases (mis)align with their own interests and values in engineering, and the extent to which this alignment relates to their persistence and career choices.

All four participants perceived technical knowledge and skills to be the most emphasized practices in their courses. Technical skills of analysis, critical thinking, and problem solving were evident in both fields, but approaches and specific knowledge necessary to solve these problems differed by field. Furthermore, all participants believed their fields included broad skills and knowledge applicable to many different industries, although Participants C and D mentioned IE did not focus as much on physical dimensions compared to other engineering disciplines. This heavy focus on technological knowledge and skills is consistent with literature that points to an often narrowly technical emphasis within engineering training [1]–[4], despite a growing acknowledgement of the importance of a broad array of comprehensive engineering skills. A persistent underemphasis on broader less technical aspects of engineering practice within engineering training has been attributed to the field's roots in positivist ideology and depoliticization of engineering, a dominant narrative excluding social and cultural considerations driving engineering work and decisions [5], [22], [65]–[69]. Interestingly, Participant B identified these ideologies as shaping the focus of the content in his engineering courses and informing his understanding of his own sense of misalignment and lack of belonging in his courses and in engineering, feeling these core cultural values of engineering were in conflict with his personal values.

Participants who described the greatest misalignment between course content and their own interests desired greater emphasis on comprehensive engineering skills and knowledge in their courses, particularly in regards to ethics, equity, sustainability and the environment, and business and human organizational philosophy. This desire for courses to address these sociotechnical aspects was discussed by Participant B; he was frustrated that courses claimed the importance of ethics but did not teach ethics and lacked social considerations in problem solving. Participants B and C noted that their elective courses discussed aspects of sociotechnical work but that there were limited curricular opportunities beyond these courses. Participant D also expressed similar dissatisfaction with his courses and experiences in IE; he felt courses focused heavily on technical skills and did not discuss diverse perspectives and ways of thinking that affect solutions and decisions. Participant D switched into IE from another engineering field, hoping for greater emphasis on business aspects of the field, but still found himself surprised and disappointed by the focus of his IE courses, feeling he didn't have many IE courses to explore human philosophy and other perspectives outside of technical practices within the major, needing to explore through consulting and business organizations. He felt unable to switch degree paths outside of engineering but decided to complete his degree finding motivation in his upper levels and ultimately pursue work in another field. His case highlights the importance for clear messaging to prospective students about the nature of engineering work that is consistent with course content in a given field. Further, his story illustrates how misalignment between course emphases and student interests can shape their intentions to persist in the field.

Across both engineering disciplines, participants identified distinctions between project-based courses and more foundationally technical focused courses. Participants A and B described how they felt their design courses, including introductory and capstone courses, were their only classes focused on technical communication, teamwork, and application of technical knowledge to engineering problems, all technical competences necessary for engineering practice [10]. Participants A, B, and D expressed the desire to incorporate more application of knowledge and project-based learning or hands-on experiences throughout the curriculum, not just in design and introductory engineering courses. Differently, Participant C felt his courses included multiple skills and knowledge that he found applicable to his research experiences, though he wished for more coding and machine learning in his courses. Still, his only mention of teamwork, by navigating group conflict and work delegation and contribution, and leadership, was in his senior design course, associating the focus of these skills in design-based courses. Students' experiences of these course emphases may reflect the common curricular structure in most engineering disciplines relegating practices such as leadership, technical communication, and teamwork to introductory and capstone design courses [70] and the need to incorporate more project-based learning and skills in technically focused courses [71], [72] .

Participants A and C felt the most alignment of their values and interests with curricular emphases of their disciplines, while Participants B and D felt misalignment between their values and interests and their discipline's. Curricular practices and messaging that align with student interests and values can heavily influence a student's ability to see themselves in future engineering careers and pursue further engineering study [13]. Participants B and D expressed how they felt their courses had little impact on shaping their future career interests and the types of jobs they wanted to pursue, while Participants A and C made connections between their engineering courses and future careers more directly. Participants B and D especially noted how they would not pursue engineering careers common in their fields after graduation but would utilize their engineering degrees and skills to carve their own paths. As the figured worlds framework suggests, the extent to which messages about the dominant forms of engineering practice in a given discipline align with students' own values and interests have implications for how students are perceived and perceive themselves as "fitting well" in the discipline. A lack of alignment with these dominant forms of practice may influence students' choices to pursue careers less closely aligned with traditional engineering work. Conversely, those whose personal engineering practice is well-aligned or valued in their discipline may be more inclined and better positioned to continue in a well-aligned traditional career path. This phenomenon was evident in our study in that Participant A had research, internship, and co-curricular opportunities that reinforced her belonging in engineering and alignment with her goals and interests in aerospace. Participants B and D needed to pursue internship and co-curricular opportunities they perceived as belonging in a niche part of engineering or outside of the engineering field altogether to advance their sociotechnical interests in non-profit community-focused sustainable engineering, and business and organizational philosophy, respectively, while Participant C was able to combine his passion for helping people with his IE interests and still align himself with IE because of his accepted research experiences in his discipline.

While all participants articulated how they planned to use and benefited from the development of technical expertise, technical communication, and problem-solving abilities from their engineering degrees in their future careers, this study illuminates the risk of students who value broader engineering skills and foregrounding societal impact in their work may be relegated to the margins of the field or leave engineering entirely. All participants, but especially Participant B and D, described their discipline's traditional engineering career paths as contrasts to what they wanted to do. This may point to a perception of lack of options or diversity of engineering career possibilities beyond what is traditionally considered. Also, if a student has interests and values that misalign with what they see as the dominant narratives for their discipline, this disconnect may influence a student's sense of belonging or force students to conform or isolate part(s) of themself from their engineering work [50], [73], [74]. Such disconnects may even perpetuate deficit narratives or harm to minoritized and marginalized students by faculty and peers [50], [75] while encouraging or validating values and interests held by the majority. One way of centering interests and values of marginalized students could be through incorporating and opportunity for these students' to connect engineering to their cultural and lived experiences [51], [54], [76]. By including intentional engagement of broader knowledge, skills, and values in engineering, more diverse student voices and needs can be centered, and reimagine who can be and what is an engineer.

5.2 Limitations

There are several limitations worth noting to provide context to our study's findings. First, the summary of our findings in the present paper is based on a small subset of our study data, representing only one data type with a fraction of our study participants. While we used this paper to explore in depth a range of perspectives expressed by students related to their course emphases and how these aligned with their own engineering goals and interests, findings from this data may differ from themes evident in our larger study. The full study includes triangulation across multiple data types (i.e., first and second interviews with over 60 participants, course observations from multiple courses in each discipline, interviews with the faculty who teach those courses, and a student survey for both disciplines) to capture curricular emphases of each discipline from a variety of sources and how these relate to student interests and career intentions.

A related limitation of this study was in diversity of participant identities. For instance, only one participant identified as a woman. Since we wanted to provide a deep narrative analysis and selected a small number of participants based on the range of alignment for each discipline, we did not achieve a full balance in demographics across participants.

Additionally, the extent to which students were able to reflect on and articulate their perspectives on how engineering course content aligned with their personal values or interests varied. While some students were readily able to discuss engineering culture and community, they sometimes struggled to reflect on what engineering practices they personally valued or thought aligned with their peers or instructors. These students discussed the extent of alignment with peers and faculty in terms of mutual desire to do well in courses, perception of instructional outcomes, or common struggle over assignments and difficulty of a class, rather than what practices they thought were valued in engineering or what practices they wished were a part of or missing from engineering. We asked follow-up questions and rephrased questions to gain further explanation regarding course emphases and students' own interests, but we needed to balance a desire for greater clarity with a need to avoid potentially leading questions and want to acknowledge some responses lacked the depth we were seeking. Social desirability may have been another factor shaping students' responses, as some may have been hesitant to critique the focus of their engineering training to others, as our study team includes faculty members in each department studied.

5.3 Implications for Educational Practice and Research

Based on these findings, we have some recommendations for engineering education practice and research. First, directly integrating and connecting broader social, economic, political, environmental, and cultural contexts into technical engineering courses to encourage critical thought, learning, and impact of engineering work in the development of comprehensive engineering skills. Supported by the ABET requirement that engineering decisions and informed judgments "must consider the impact of engineering solutions in global, economic, environmental, and societal contexts" [30], there is ample opportunity, desire, and need for engineering courses to expand and more explicitly incorporate comprehensive knowledge and skill development in course instruction through case studies [77]–[79], explicit activities in projects and problem-solving to think about stakeholders and how broader contexts affect engineering work [67], [80], [81], engineer positionality and reflection on their decisions and identities as it relates to their work [33], [82]–[84], and assessments and tools [31], [85].

Additionally, there is a growing body of work in incorporating sociotechnical knowledge and skills in more technically focused engineering courses [86]–[90]. A recent study by Judge, Finelli, and Lord (2022) included the design and study of a sociotechnical module for exploring the implications of and building skills in social responsibility with learning objectives, pre-class, in-class, and post-class activities to connect the broader social, environmental, and political contexts surrounding electric vehicle technologies for a circuits course [88]. While this module is still being studied for its impact on developing sociotechnical skills, it is a starting point for integrating sociotechnical content into engineering technical courses, and we would be interested to see the research, practice, and impacts of expanding this content into other concepts, courses, and engineering disciplines.

Secondly, in addition to broadening engineering knowledge and skills, engineering programs also need to broaden communication of career opportunities and career options for engineering students beyond a discipline's traditional engineering careers. This will be especially important for students who seek a larger impact of their work in solving today's world problems or have values or interests that misalign with curricular messaging in their courses.

Thirdly, this study looked at one large, Midwestern university and two engineering disciplines. In order to develop a deeper understanding of practices, values, and interests of engineering students and their future plans, we must look at a greater variety of universities and colleges, students' interests and needs, and how students (mis)align with their respective discipline. This work complements and extends existing work on undergraduate engineering students' motivations for studying engineering, but expanding upon the curricular content and impact will only benefit the field, help understand ways of retaining diverse students, and enhance outcomes of engineering courses and programs.

6. Conclusions

In this study, we compared curricular messaging perceived by two industrial engineering and two mechanical engineering students via semi-structured interviews about what they saw as valued practices central to their respective engineering discipline. Guided by the figured worlds theoretical framework, we analyzed how these practices aligned with student interests and values in engineering, extent of recognition by peers and faculty of important skills and knowledge, and how these factors impacted student career choices and interests. Participants reported technical knowledge, problem-solving, teamwork, and technical communication were most emphasized across the two disciplines. Students with the most misalignment of practices in their field desired more sociotechnical skills and development, which was underemphasized or almost entirely nonexistent in most engineering courses, and desired careers focused on integrating these skills and creating pathways beyond more traditional engineering careers. This work supports development of sociotechnical skills and knowledge through engineering curriculum and can be further expanded to explore curricular messaging of engineering practices to other engineering disciplines and university contexts.

Acknowledgements

This material is based upon work supported by the National Science Foundation Discipline-Based Education Research within the EHS Core Research Program under Grant No. 2054823 and Graduate Research Fellowship Program under Grant No. DGE 1841052. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

[1] J. Duderstadt, "Engineering for a changing world: A roadmap to the future of engineering practice, research, and education.," *Ann Arbor MI Millenn. Proj.*, 2008, Accessed: Aug. 30, 2011. [Online]. Available: http://milproj.dc.umich.edu/.

[2] D. F. Radcliffe, "Shaping the Discipline of Engineering Education," *J. Eng. Educ.*, vol. 95, no. 4, pp. 263–264, Oct. 2006, [Online]. Available: https://doi.org/10.1002/j.2168-9830.2006.tb00901.x

[3] G. L. Downey and J. C. Lucena, “Knowledge and professional identity in engineering: code-switching and the metrics of progress,” *Hist. Technol.*, vol. 20, no. 4, pp. 393–420, Dec. 2004, doi: 10.1080/0734151042000304358.
[4] J. Mills and D. Treagust, “Engineering education - Is problem-based or project-based learning the answer?,” *Australas. Assoc. Eng. Educ.*, vol. 3, 2003.
[5] W. Faulkner, “`Nuts and Bolts and People’: Gender-Troubled Engineering Identities,” *Soc. Stud. Sci.*, vol. 37, no. 3, pp. 331–356, Jun. 2007, doi: 10.1177/0306312706072175.
[6] R. Martin, B. Maytham, J. Case, and D. Fraser, “Engineering graduates’ perceptions of how well they were prepared for work in industry,” *Eur. J. Eng. Educ.*, vol. 30, no. 2, pp. 167–180, May 2005, doi: 10.1080/03043790500087571.
[7] E. Cech, C. Finelli, E. Goldenkoff, and T. Davis, “Does Public Welfare Responsibility Training in Engineering Education Shape Engineering Professionals’ Reasoning about Ethical Issues?,” presented at the 2022 ASEE Annual Conference & Exposition, Aug. 2022. Accessed: Jan. 27, 2023. [Online]. Available: https://peer.asee.org/does-public-welfare-responsibility-training-in-engineering-education-shape-engineering-professionals-reasoning-about-ethical-issues
[8] R. S. Adams, J. Turns, and C. J. Atman, “Educating effective engineering designers: the role of reflective practice,” *Des. Stud.*, vol. 24, no. 3, pp. 275–294, May 2003, doi: 10.1016/S0142-694X(02)00056-X.
[9] S. A. Male, “Generic engineering competencies: A review and modelling approach,” *Educ. Res. Perspect.*, vol. 37, no. 1, pp. 25–51, 2010, Accessed: Feb. 10, 2023. [Online]. Available: https://www.erpjournal.net/wp-content/uploads/2020/01/ERPV37-1_Male-S.-2010.-Generic-Engineering-Competencies.pdf
[10] H. J. Passow and C. H. Passow, “What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review: Undergraduate Engineering Competencies: A Sytematic Review,” *J. Eng. Educ.*, vol. 106, no. 3, pp. 475–526, Jul. 2017, doi: 10.1002/jee.20171.
[11] J. Qadir, K.-L. A. Yau, M. Ali Imran, and A. Al-Fuqaha, “Engineering Education, Moving into 2020s : Essential Competencies for Effective 21st Century Electrical & Computer Engineers,” in *2020 IEEE Frontiers in Education Conference (FIE)*, Oct. 2020, pp. 1–9. doi: 10.1109/FIE44824.2020.9274067.
[12] K. Litchfield and A. Javernick-Will, “‘I Am an Engineer AND’: A Mixed Methods Study of Socially Engaged Engineers,” *J. Eng. Educ.*, vol. 104, no. 4, pp. 393–416, Oct. 2015, doi: 10.1002/jee.20102.
[13] H. M. Matusovich, R. A. Streveler, and R. L. Miller, “Why Do Students Choose Engineering? A Qualitative, Longitudinal Investigation of Students’ Motivational Values,” *J. Eng. Educ.*, vol. 99, no. 4, pp. 289–303, Oct. 2010, doi: 10.1002/j.2168-9830.2010.tb01064.x.
[14] C. Swan, K. Paterson, and A. R. Bielefeldt, “Community engagement in engineering education as a way to increase inclusiveness,” in *Cambridge Handbook of Engineering Education*, A. Johri and B. Olds, Eds., Cambridge: Cambridge University Press, 2014, pp. 357–372.
[15] B. Bakka *et al.*, “Queering Engineering Through a Student Driven LGBTQIA+ Reading Group (Experience),” in *2021 ASEE Annual Conference*, 2021, p. 16.
[16] W. Colvin, S. Lyden, and B. A. León de la Barra, “Attracting Girls to Civil Engineering through Hands-On Activities That Reveal the Communal Goals and Values of the

Profession," *Leadersh. Manag. Eng.*, vol. 13, no. 1, pp. 35–41, Jan. 2013, doi: 10.1061/(ASCE)LM.1943-5630.0000208.
[17] A. Wilson-Lopez, J. A. Mejia, I. M. Hasbún, and G. S. Kasun, "Latina/o Adolescents' Funds of Knowledge Related to Engineering: Latina/o Adolescents' Funds of Knowledge Related to Engineering," *J. Eng. Educ.*, vol. 105, no. 2, pp. 278–311, Apr. 2016, doi: 10.1002/jee.20117.
[18] J. C. Garibay, "STEM students' social agency and views on working for social change: Are STEM disciplines developing socially and civically responsible students? - Garibay - 2015 - Journal of Research in Science Teaching - Wiley Online Library," *J. Res. Sci. Teach.*, vol. 52, no. 5, pp. 610–632, 2015, Accessed: Apr. 10, 2023. [Online]. Available: https://onlinelibrary.wiley.com/doi/full/10.1002/tea.21203
[19] A. B. Diekman, E. K. Clark, A. M. Johnston, E. R. Brown, and M. Steinberg, "Malleability in communal goals and beliefs influences attraction to stem careers: evidence for a goal congruity perspective," *J. Pers. Soc. Psychol.*, vol. 101, no. 5, pp. 902–918, Nov. 2011, doi: 10.1037/a0025199.
[20] E. Mosyjowski, "Engineering for Social Good? How Professional and Educational Experiences Inform Engineers' Solutions to Complex Problems," University of Michigan, 2020.
[21] J. L. Smith, E. Cech, A. Metz, and M. Huntoon, "Giving back or giving up: Native american student experiences in science and engineering," *Cultur. Divers. Ethnic Minor. Psychol.*, vol. 20, no. 3, pp. 413–429, 2014.
[22] E. A. Cech, "The (Mis)Framing of Social Justice: Why Ideologies of Depoliticization and Meritocracy Hinder Engineers' Ability to Think About Social Injustices," in *Engineering Education for Social Justice*, J. Lucena, Ed., in Philosophy of Engineering and Technology, vol. 10. Dordrecht: Springer Netherlands, 2013, pp. 67–84. doi: 10.1007/978-94-007-6350-0_4.
[23] B. Palmer, P. Terenzini, A. McKenna, B. Harper, and D. Merson, "Design in Context: Where do the Engineers of 2020 Learn this Skill?," in *2011 ASEE Annual Conference & Exposition Proceedings*, Vancouver, BC: ASEE Conferences, Jun. 2011, p. 22.430.1-22.430.26. doi: 10.18260/1-2--17711.
[24] A. E. Slaton, "Meritocracy, technocracy, democracy: Understandings of racial and gender equity in american engineering education," in *International Perspectives on Engineering Education*, S. Christensen, C. Didier, A. Jamison, M. Meganck, C. Mitcham, and B. Newberry, Eds., in Philosophy of Engineering and Technology, no. 20. Springer, Cham, 2015, pp. 171–189.
[25] H. K. Ro, D. Merson, L. R. Lattuca, and P. T. Terenzini, "Validity of the Contextual Competence Scale for Engineering Students," *J. Eng. Educ.*, vol. 104, no. 1, pp. 35–54, 2015.
[26] E. A. Cech and H. M. Sherick, "Depoliticization and the Structure of Engineering Education," in *International Perspectives on Engineering Education: Engineering Education and Practice in Context, Volume 1*, S. H. Christensen, C. Didier, A. Jamison, M. Meganck, C. Mitcham, and B. Newberry, Eds., in Philosophy of Engineering and Technology. Cham: Springer International Publishing, 2015, pp. 203–216. doi: 10.1007/978-3-319-16169-3_10.

[27] F. O. Karatas, A. Micklos, and G. M. Bodner, “Sixth-grade students’ views of the nature of engineering and images of engineers,” *J. Sci. Educ. Technol.*, vol. 20, no. 2, pp. 123–135, 2011.
[28] R. P. Loweth, S. R. Daly, L. Paborsky, S. L. Hoffman, and S. J. Skerlos, “‘You Could Take “Social” Out of Engineering and Be Just Fine’: An Exploration of Engineering Students’ Beliefs About the Social Aspects of Engineering Work,” presented at the 2021 ASEE Virtual Annual Conference Content Access, Jul. 2021. Accessed: Feb. 15, 2023. [Online]. Available: https://peer.asee.org/you-could-take-social-out-of-engineering-and-be-just-fine-an-exploration-of-engineering-students-beliefs-about-the-social-aspects-of-engineering-work
[29] National Academy of Engineering, *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, DC: National Academy of Engineering, 2004. Accessed: Apr. 30, 2014. [Online]. Available: http://www.nap.edu/catalog.php?record_id=10999
[30] ABET, “Criteria for Accrediting Engineering Programs: Effective for Evaluations during the 2022-2023 Accreditation Cycle,” ABET, Inc., Baltimore, MD, 2021. Accessed: Feb. 15, 2023. [Online]. Available: https://www.abet.org/wp-content/uploads/2022/01/2022-23-EAC-Criteria.pdf
[31] A. Mazzurco and S. Daniel, “Socio-technical thinking of students and practitioners in the context of humanitarian engineering,” *J. Eng. Educ.*, vol. 109, no. 2, pp. 243–261, Apr. 2020, Accessed: Feb. 15, 2023. [Online]. Available: https://doi.org/10.1002/jee.20307
[32] G. L. Downey *et al.*, “The Globally Competent Engineer: Working Effectively with People Who Define Problems Differently,” *J. Eng. Educ.*, vol. 95, no. 2, pp. 107–122, 2006.
[33] J. Schneider, J. A. Leydens, and J. Lucena, “Where is ‘Community’?: Engineering education and sustainable community development,” *Eur. J. Eng. Educ.*, vol. 33, no. 3, pp. 307–319, Jun. 2008, doi: 10.1080/03043790802088640.
[34] S. R. Daly, E. A. Mosyjowski, and C. M. Seifert, “Teaching Creativity in Engineering Courses,” *J. Eng. Educ.*, vol. 103, no. 3, pp. 417–449, Jul. 2014, doi: 10.1002/jee.20048.
[35] J. Gardner, *Assessment and Learning*. SAGE, 2006.
[36] A. Martone and S. G. Sireci, “Evaluating Alignment Between Curriculum, Assessment, and Instruction,” *Rev. Educ. Res.*, vol. 79, no. 4, pp. 1332–1361, Dec. 2009, doi: 10.3102/0034654309341375.
[37] G. P. Wiggins and J. McTighe, *Understanding by Design*. ASCD, 2005.
[38] L. R. Lattuca, D. B. Knight, H. K. Ro, and B. J. Novoselich, “Supporting the Development of Engineers’ Interdisciplinary Competence,” *J. Eng. Educ.*, vol. 106, no. 1, pp. 71–97, 2017, doi: 10.1002/jee.20155.
[39] J. A. Leydens and J. C. Lucena, “Social Justice: A Missing, Unelaborated Dimension in Humanitarian Engineering and Learning through Service,” *Int. J. Serv. Learn. Eng.*, vol. 9, no. 2, 2014.
[40] S. Niles, S. Contreras, S. Roudbari, J. Kaminsky, and J. L. Harrison, “Resisting and assisting engagement with public welfare in engineering education,” *J. Eng. Educ.*, vol. 109, no. 3, pp. 491–507, 2020, doi: 10.1002/jee.20323.
[41] C. G. P. Berdanier, X. Tang, and M. F. Cox, “Ethics and Sustainability in Global Contexts: Studying Engineering Student Perspectives Through Photoelicitation,” *J. Eng. Educ.*, vol. 107, no. 2, pp. 238–262, 2018, doi: 10.1002/jee.20198.
[42] J. McCabe, “Racial and Gender Microaggressions on a Predominantly-White Campus: Experiences of Black, Latina/o and White Undergraduates,” *Race Gend. Cl.*, vol. 16, no.

1/2, pp. 133–151, 2009, Accessed: Apr. 03, 2023. [Online]. Available: https://www.jstor.org/stable/41658864
[43] B. R. Silver, “Inequality in the Extracurriculum: How Class, Race, and Gender Shape College Involvement1,” *Sociol. Forum*, vol. 35, no. 4, pp. 1290–1314, 2020, doi: 10.1111/socf.12648.
[44] N. Winstone, K. Balloo, K. Gravett, D. Jacobs, and H. Keen, “Who stands to benefit? Wellbeing, belonging and challenges to equity in engagement in extra-curricular activities at university,” *Act. Learn. High. Educ.*, vol. 23, no. 2, pp. 81–96, Jul. 2022, doi: 10.1177/1469787420908209.
[45] A. Liu, “Unraveling the myth of meritocracy within the context of US higher education,” *High. Educ.*, vol. 62, no. 4, pp. 383–397, Oct. 2011, doi: 10.1007/s10734-010-9394-7.
[46] C. C. Samuelson and E. Litzler, “Community cultural wealth: An assets-based approach to persistence of engineering students of color,” *J. Eng. Educ.*, vol. 105, no. 1, pp. 93–117, 2015.
[47] E. Cech, “Engineers and Engineeresses? Self-conceptions and the Development of Gendered Professional Identities,” *Sociol. Perspect.*, vol. 58, no. 1, pp. 56–77, Mar. 2015, doi: 10.1177/0731121414556543.
[48] B. Benedict, D. Verdín, A. Godwin, and T. Milton, “Social and latent identities that contribute to diverse students’ belongingness in engineering,” in *2017 IEEE Frontiers in Education Conference (FIE)*, Oct. 2017, pp. 1–5. doi: 10.1109/FIE.2017.8190644.
[49] M. A. Eisenhart and E. Finkel, *Women’s Science: Learning and Succeeding from the Margins*. Chicago, IL: University of Chicago Press, 1998. Accessed: Feb. 15, 2023. [Online]. Available: https://press.uchicago.edu/ucp/books/book/chicago/W/bo3683343.html
[50] E. Blosser, “An examination of Black women’s experiences in undergraduate engineering on a primarily white campus: Considering institutional strategies for change,” *J. Eng. Educ.*, vol. 109, no. 1, pp. 52–71, Jan. 2020, doi: 10.1002/jee.20304.
[51] D. Riley, A. E. Slaton, and A. L. Pawley, “Social Justice and Inclusion: Women and Minorities in Engineering,” in *Cambridge Handbook of Engineering Education Research*, A. Johri and B. M. Olds, Eds., Cambridge: Cambridge University Press, 2014, pp. 335–356. doi: 10.1017/CBO9781139013451.022.
[52] S. M. Lord, M. W. Ohland, R. A. Layton, and M. M. Camacho, “Beyond pipeline and pathways: Ecosystem metrics,” *J. Eng. Educ.*, vol. 108, no. 1, pp. 32–56, Jan. 2019, doi: 10.1002/jee.20250.
[53] R. Marra, B. Bogue, D. Shen, and K. Rodgers, “Those That Leave — Assessing Why Students Leave Engineering,” presented at the 2007 Annual Conference & Exposition, Jun. 2007, p. 12.1490.1-12.1490.15. Accessed: Jan. 23, 2023. [Online]. Available: https://peer.asee.org/those-that-leave-assessing-why-students-leave-engineering
[54] E. McGee and L. Bentley, “The Equity Ethic: Black and Latinx College Students Reengineering Their STEM Careers toward Justice,” *Am. J. Educ.*, vol. 124, no. 1, pp. 1–36, Nov. 2017, doi: 10.1086/693954.
[55] J. C. Lucena, “Making Women and Minorities in Science and Engineering For National Purposes in the United States,” *J. Women Minor. Sci. Eng.*, vol. 6, no. 1, pp. 1–31, 2000.
[56] L. M. Frehill, N. M. Di Fabio, S. T. Hill, K. Traeger, and J. Buono, “Women in engineering: A review of the 2007 literature,” *SWE Magazine*, vol. 54, pp. 34–70, Jun. 2008.

[57] E. Litzler and C. Samuelson, "Deciding to stay: The intersection of sex and race/ethnicity," in *2013 IEEE Frontiers in Education Conference (FIE)*, Oct. 2013, pp. 1812–1818. doi: 10.1109/FIE.2013.6685150.
[58] D. C. Holland, W. S. Lachicotte Jr., D. Skinner, and C. Cain, "Chapter 3: Figured Worlds," in *Identity and Agency in Cultural Worlds*, Cambridge, Mass.: Harvard Univ. Press, 1998.
[59] A. Leontiev, *Activity, Consciousness, Personality*. Englewood Cliffs, NJ: Prentice-Hall, 1978.
[60] L. R. Lattuca and J. S. Stark, *Shaping the college curriculum: Academic plans in context*, 2nd ed. San Francisco, CA: Jossey-Bass Inc., 2009.
[61] J. Smart, K. Feldman, and C. Ethington, *Academic disciplines: Holland's theory and the study of college students and faculty*. Nashville, TN: Vanderbilt University Press, 2000.
[62] J. Maxwell, "Qualitative Research Design : An Interactive Approach / J.A. Maxwell.," Jan. 2012.
[63] M. Q. Patton and M. Q. Patton, *Qualitative research and evaluation methods*, 3 ed. Thousand Oaks, Calif: Sage Publications, 2002.
[64] J. W. Creswell, *Research design: qualitative, quantitative, and mixed methods approaches*, 4th ed. Thousand Oaks: SAGE Publications, 2014.
[65] D. F. Carter, J. E. Razo Dueñas, and R. Mendoza, "Critical Examination of the Role of STEM in Propagating and Maintaining Race and Gender Disparities," in *Higher Education: Handbook of Theory and Research*, M. B. Paulsen and L. W. Perna, Eds., in Higher Education: Handbook of Theory and Research, vol. 34. Cham: Springer International Publishing, 2019, pp. 39–97. doi: 10.1007/978-3-030-03457-3_2.
[66] J. A. Leydens and J. Lucena, "Integrating social justice into engineering education from the margins: guidelines for addressing sources of faculty resistance to social justice education," in *Engineering Education for Social Justice*, Springer, 2013.
[67] J. A. Leydens and J. C. Lucena, *Engineering Justice: Transforming Engineering Education and Practice*. Hoboken, NJ: Wiley & Sons, 2017.
[68] D. Riley, *Engineering and Social Justice*. Morgan & Claypool, 2008.
[69] R. Williams, *Retooling: A Historian Confronts Technological Change*. MIT Press, 2002. doi: 10.7551/mitpress/5935.001.0001.
[70] D. Knight and D. Kotys-Schwartz, "Once again around the double triangle: A multi-rater assessment of capstone design skills," in *2013 IEEE Frontiers in Education Conference (FIE)*, Oct. 2013, pp. 1018–1020. doi: 10.1109/FIE.2013.6684980.
[71] R. N. Savage, J. Stolk, and L. Vanasupa, "Collaborative Design of Project-Based Learning Courses: How to Implement a Mode of Learning That Effectively Builds Skills for the Global Engineer," in *Proceedings of the American Society for Engineering Education Annual Conference: Honolulu, HI*, Honolulu, HI, Jun. 2007.
[72] R. Savage, K. Chen, and L. Vanasupa, "Integrating Project-based Learning throughout the Undergraduate Engineering Curriculum," *J. STEM Educ.*, vol. 8, no. 3, Mar. 2008, Accessed: Feb. 15, 2023. [Online]. Available: https://www.learntechlib.org/p/173698/
[73] E. A. Cech and W. R. Rothwell, "LGBTQ Inequality in Engineering Education," *J. Eng. Educ.*, vol. 107, no. 4, pp. 583–610, 2018, doi: 10.1002/jee.20239.
[74] B. E. Hughes, "'Managing by Not Managing': How Gay Engineering Students Manage Sexual Orientation Identity," *J. Coll. Stud. Dev.*, vol. 58, no. 3, pp. 385–401, 2017, doi: 10.1353/csd.2017.0029.

[75] M. M. Camacho and S. M. Lord, Eds., “The borderlands of education: latinas in engineering,” in *The Borderlands of Education: Latinas in Engineering*, Lanham: Lexington Books, 2013.
[76] D. Verdín, A. Godwin, and B. Capobianco, “Systematic Review of the Funds of Knowledge Framework in STEM Education,” in *2016 ASEE Annual Conference & Exposition Proceedings*, New Orleans, Louisiana: ASEE Conferences, Jun. 2016, p. 25999. doi: 10.18260/p.25999.
[77] Z. Bagdasarov *et al.*, “Case-based ethics instruction: The influence of contextual and individual factors in case content on ethical decision-making,” *Sci. Eng. Ethics*, vol. 19, no. 3, pp. 1305–1322, 2013.
[78] S. Luster-Teasley, S. C. Hargrove-Leak, and W. Gibson, “Making the case: adding case studies to an environmental engineering laboratory to increase student engagement, learning, and data analysis,” presented at the ASEE, New Orleans, LA, New Orleans, LA, 2016. doi: 10.18260/p.25669.
[79] D. Nieusma and D. Riley, “Designs on development: engineering, globalization, and social justice,” *J. Eng. Stud.*, vol. 2, no. 1, pp. 29–59, 2010.
[80] K. H. Sienko *et al.*, “Global Health Design: Clinical Immersion, Opportunity Identification and Definition, and Design Experiences,” *Int. J. Eng. Educ.*, vol. 34, no. 2(B), pp. 780–800, 2018.
[81] I. B. Rodriguez-Calero, M. J. Coulentianos, S. R. Daly, J. Burridge, and K. H. Sienko, “Prototyping strategies for stakeholder engagement during front-end design: Design practitioners’ approaches in the medical device industry,” *Des. Stud.*, vol. 71, p. 100977, Nov. 2020, doi: 10.1016/j.destud.2020.100977.
[82] J. A. Mejia, R. A. Revelo, I. Villanueva, and J. Mejia, “Critical Theoretical Frameworks in Engineering Education: An Anti-Deficit and Liberative Approach,” *Educ. Sci.*, vol. 8, no. 4, Art. no. 4, Dec. 2018, doi: 10.3390/educsci8040158.
[83] J. A. Turns, B. Sattler, K. Yasuhara, J. L. Borgford-Parnell, and C. J. Atman, “Integrating Reflection into Engineering Education,” presented at the 2014 ASEE Annual Conference & Exposition, Jun. 2014, p. 24.776.1-24.776.16. Accessed: Apr. 04, 2023. [Online]. Available: https://peer.asee.org/integrating-reflection-into-engineering-education
[84] N. Walji, P. K. Sheridan, P. Kinnear, R. Irish, and J. Foster, “WHO YOU ARE AND HOW YOU WORK: EMBEDDING POSITIONALITY IN ENGINEERING DESIGN,” *Proc. Can. Eng. Educ. Assoc. CEEA*, Jun. 2020, doi: 10.24908/pceea.vi0.14209.
[85] S. Yilmaz, C. M. Seifert, and R. Gonzalez, “Cognitive heuristics in design: Instructional strategies to increase creativity in idea generation,” *Artif. Intell. Eng. Des. Anal. Manuf.*, vol. 24, no. 3, pp. 335–355, Aug. 2010, doi: 10.1017/S0890060410000235.
[86] G. D. Hoople and A. Choi-Fitzpatrick, *Drones for Good: How to Bring Sociotechnical Thinking into the Classroom*. in Synthesis Lectures on Engineers, Technology, & Society. Cham: Springer International Publishing, 2020. doi: 10.1007/978-3-031-02116-9.
[87] G. D. Hoople, D. A. Chen, S. M. Lord, L. A. Gelles, F. Bilow, and J. A. Mejia, “An Integrated Approach to Energy Education in Engineering,” *Sustainability*, vol. 12, no. 21, Art. no. 21, Jan. 2020, doi: 10.3390/su12219145.
[88] G. Judge, C. Finelli, and S. Lord, “Development of a Sociotechnical Module Exploring Electric Vehicle Batteries for a Circuits Course,” presented at the 2022 ASEE Annual Conference & Exposition, Aug. 2022. Accessed: Jan. 27, 2023. [Online]. Available:

https://peer.asee.org/development-of-a-sociotechnical-module-exploring-electric-vehicle-batteries-for-a-circuits-course
[89] S. M. Lord, B. Przestrzelski, and E. Reddy, “Teaching Social Responsibility in a Circuits Course,” presented at the 2019 ASEE Annual Conference & Exposition, Jun. 2019. Accessed: Feb. 15, 2023. [Online]. Available: https://peer.asee.org/teaching-social-responsibility-in-a-circuits-course
[90] B. Przestrzelski, E. Reddy, and S. M. Lord, “Mission Possible: Blending the social and technical through an innovative biodesign challenge module for a Materials Science class,” in *2018 IEEE Frontiers in Education Conference (FIE)*, Oct. 2018, pp. 1–7. doi: 10.1109/FIE.2018.8658942.