Celebrating the Skeptics: Funds of Knowledge as a Critique of Engineering Epistemologies

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Abstract

Engineering educators use the funds of knowledge (FOK) approach to identify and build upon the knowledge that students develop and bring with them from their experiences growing up in particular households and communities. Existing research shows that understanding students in the context of their longer life histories and belongingness in wider communities provides an asset-based approach for enhancing belongingness, especially for students from historically under-represented and historically marginalized backgrounds. This paper takes a different approach by showing how a FOK approach to learning can also open up spaces for students to critique problematic assumptions that are built into dominant engineering epistemologies. It does so by comparing two different efforts to integrate FOK into engineering programs at the same university. The first focused on engineering students enrolled in a humanitarian engineering and science graduate program that encourages sociotechnical thinking and practice. The second used an FOK approach to bring together welding students from a community college and undergraduate metallurgical engineering students to work together on a shared design project. We find that the project helped the engineering students appreciate the FOK of the welding students, laying the groundwork for greater mutual understanding and respect.

Introduction

Engineering remains a profession that is dominated by white, able-bodied heterosexual men, despite decades of efforts to broaden participation and support the success of students from other backgrounds [1]. Enhancing minoritized students' senses of belonging – in both engineering as a field and in its educational institutions – is frequently promoted as a strategy to recruit and support more diverse engineering students [2], [3], [4], [5], [6]. These calls are bolstered by compelling narratives from students wishing they belonged in engineering [7], [8]. In our reading of the engineering education literature on belonging, however, we note a largely unacknowledged, underlying normative judgement about belonging: belonging is *good* while a lack of belonging in engineering is *bad*, largely because it leads to under-enrollment and attrition. This judgement is well intentioned, as it seeks to promote participation in a lucrative field by those who have been traditionally excluded from it. In fact, some of us have promoted this reasoning in our own research [6], [8], [9].

In this paper, however, we argue for the importance of revisiting this normative judgement about belonging in engineering. Reading enthusiastic calls to find ways to bolster minoritized students' belongingness in engineering *alongside* trenchant critiques of the harms and limitations of engineering can feel like whiplash. Engineering has served as a crucial tool for empire building, war, and the expansion of predatory capitalism [10], [11], [12], [13], [14], [15]. Mainstream engineering education itself normalizes and privileges whiteness while disavowing the significance of race [16], [17], [18], [19], constituting a key example of colorblind racism [20].

When the paradox of encouraging participation in an often problematic profession is recognized, attempts to reconcile it hinge on imagining engineering differently: perhaps if more minoritized students persisted in engineering, the logic goes, engineering itself would be different – better, more responsible – because they are more motivated by improving their communities [21].

In this paper, we share and reflect on an asset-based approach to *facilitating belonging through questioning engineering itself*. Approaches that treat students' backgrounds as assets rather than as liabilities show promise for enhancing minoritized students' interest and belonging in engineering [22]. Key among these are funds of knowledge (FOK), which refers to the "historically accumulated and culturally developed bodies of knowledge, skills, and personal/social identifications embedded in particular geographical spaces, social institutions, or any educational resource available in any community" [23], [24], [25]. Community cultural wealth similarly emphasizes the "array of cultural knowledge, skills, abilities and contacts possessed by socially marginalized groups that often go unrecognized and unacknowledged" [26], treating these as forms of capital that students can leverage.

In what follows, we show how two FOK-inspired educational research projects intervened in dominant engineering epistemologies, opening up space to support minoritized students via rethinking engineering itself. Both approaches encouraged "technoskeptical thinking," or the "ability to think about technologies as more than neutral tools and analyze their complex interactions with sociotechnical systems and values" [27]. The first project involves an interdiscipinary graduate program that explicitly encourages STEM-trained students to question the history and politics of their fields. Students learned to map their own FOK and draw connections between those knowledges and their graduate coursework. Survey and interview data suggest that these activities, in the context of their graduate program, enhanced belongingness among minoritized students. The second used an FOK approach to bring together welding students from a community college and undergraduate metallurgical engineering students to work together on a shared design project that required both sets of knowledge. Student reflections suggest that the project helped the engineering students appreciate the FOK of the welding students, which are otherwise de-emphasized in mainstream four-year programs. We conclude by drawing out the double bind suggested by our findings: questioning engineering may enhance minoritized students' senses of belonging in engineering, but it also potentially erodes their external recognition as engineers.

Methodology and student profiles

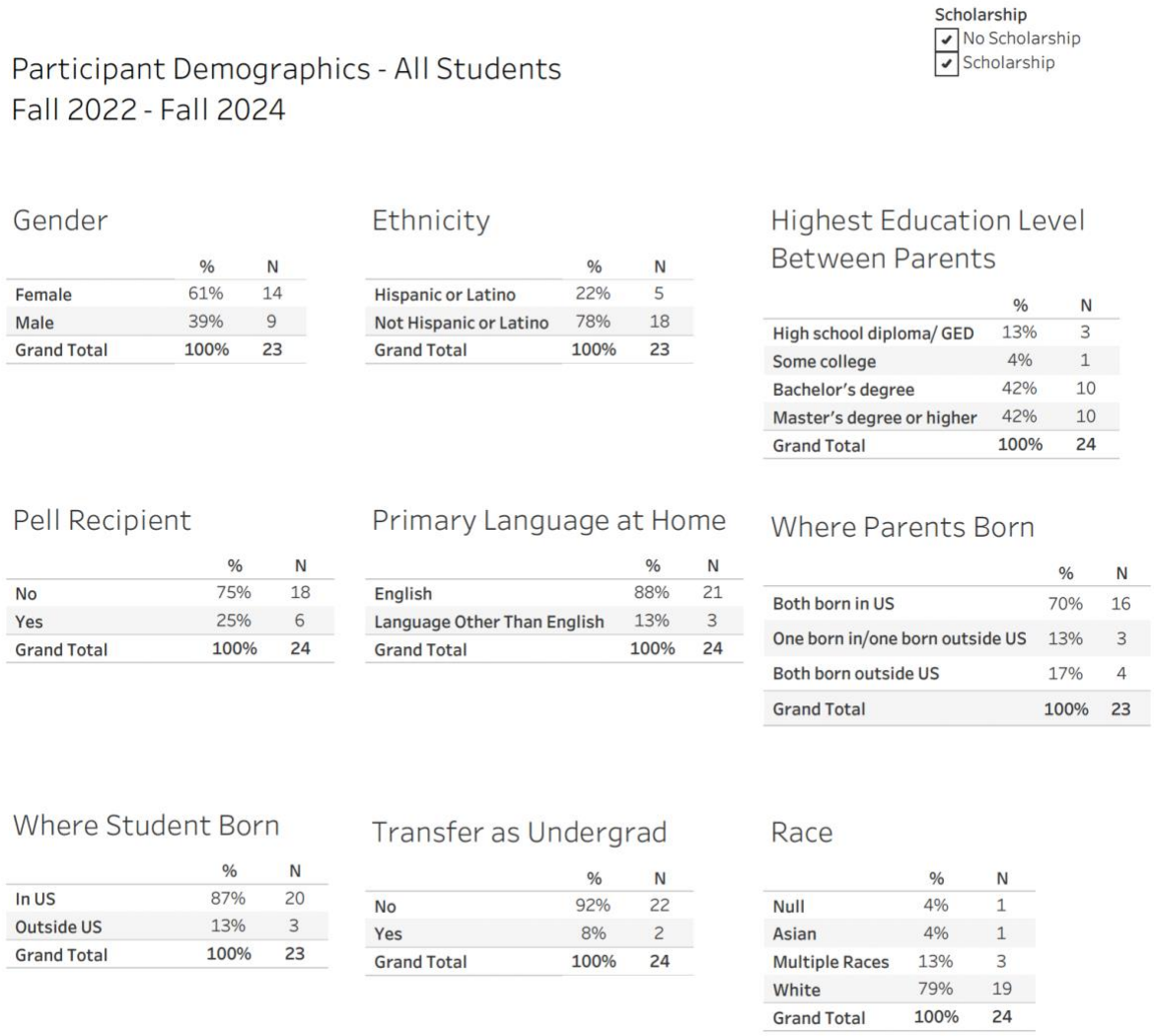
Student group 1: Sociotechnical graduate students

Four of us serve as faculty for the Colorado School of Mines' (Mines) Humanitarian Engineering and Science (HES) master's program that is based in a sociotechnical approach to STEM, with a focus on direct engagement with communities to promote sustainability and social justice. Half

of their courses are grounded in the social sciences (with a strong emphasis on science and technology studies), and the other half come from a chosen engineering or applied science disciplinary track, such as environmental engineering or geophysics. All new students who enroll in the graduate program participate in an orientation at the annual entry point in the fall semester. As a part of that orientation, students participate in a session on FOK that introduces the concept, invites students to start mapping their own FOK, and provides opportunities for students to share those FOK with their peers and program faculty members. In a required first year class, they also complete an assignment where they chart how their familial and community backgrounds shaped their decisions to study science or engineering, their many forms of knowledge (formal, experiential, tacit, etc.), and their political desires to make a difference in the world. Similar assignments are also present in other courses. Students also have the opportunity to participate in mentorship circles, which connects first-year students with upper-year peer and faculty mentors to explore strategies for leveraging their own FOK to handle key challenges and develop new skills around the graduate transition, time management and prioritization, building and working with an advisor team, and putting theory into practice. Finally, FOK-themed programming provides the opportunity for students to meet external faculty who conduct research on FOK in engineering and to network with alumni of the program.

Before the orientation, all students take a survey that tracks students' FOK as well as graduation certainty, belongingness, engineering role identity, and demographic information. The survey was previously developed and validated as part of another NSF grant and is available open access [28]. The survey was administered by our external evaluator, who also removed identifying information and sorted the data for the faculty team to examine. Students took the same survey after they graduated, to help the team assess changes over time. A subset of our students who have demonstrated unmet financial need receive a scholarship funded by the NSF S-STEM program. (At the graduate level, demonstration of unmet financial need does not exactly track with socioeconomic status, given that students who are recently independent for tax purposes may have significant unmet need, as they no longer claim their parents' income, even if they grew up in a privileged household.) Students who received the S-STEM scholarship participate in an exit interview with either the external evaluator or a program faculty member who is not their primary advisor. The interview covers how students understand their FOK, how they view the connections between their FOK and their graduate experience, how they experience belongingness in their graduate program and in the wider STEM field, and how they view their own professional identity. The interviews are all recorded, transcribed, and anonymized.

This paper analyzes data from the first two cohorts of students. It includes 23 students, of whom ten completed the exit interview as scholarship students; demographics are provided in Figure 1. One limitation of our study is that non-scholarship students do not complete the exit interview, meaning that our qualitative analysis focuses on the experiences of scholarship students.



Gender	%	N
Female	61%	14
Male	39%	9
Grand Total	100%	23

Ethnicity	%	N
Hispanic or Latino	22%	5
Not Hispanic or Latino	78%	18
Grand Total	100%	23

Highest Education Level Between Parents	%	N
High school diploma/ GED	13%	3
Some college	4%	1
Bachelor's degree	42%	10
Master's degree or higher	42%	10
Grand Total	100%	24

Pell Recipient	%	N
No	75%	18
Yes	25%	6
Grand Total	100%	24

Primary Language at Home	%	N
English	88%	21
Language Other Than English	13%	3
Grand Total	100%	24

Where Parents Born	%	N
Both born in US	70%	16
One born in/one born outside US	13%	3
Both born outside US	17%	4
Grand Total	100%	23

Where Student Born	%	N
In US	87%	20
Outside US	13%	3
Grand Total	100%	23

Transfer as Undergrad	%	N
No	92%	22
Yes	8%	2
Grand Total	100%	24

Race	%	N
Null	4%	1
Asian	4%	1
Multiple Races	13%	3
White	79%	19
Grand Total	100%	24

Figure 1: Demographic profile of sociotechnical graduate students. Note: Non-binary options were given for gender, but they were not selected by students.

Student group 2: MME students and welding students

As a part of Klemm-Toole's CAREER grant, he brought together metallurgical and materials engineering (MME) students from Mines and welding students at Front Range Community College. They completed a joint capstone project that required the unique knowledge of both sets of students. They worked in mixed groups with automated arc welding equipment to additively manufacture a structure or component of their choosing. The flexible project direction facilitated each student expressing their interest areas and revealed what knowledge and experience they brought from their own backgrounds, such as intuition about influences of welding torch angle (welders) or robot programming methods (engineers).

This paper reports on two iterations of the project with two different student groups. Students were introduced to the FOK concept during the first day of the joint project and had the

opportunity to map their own FOK and learn about each other's FOK. Faculty and the external examiner collected the students' FOK maps. Throughout the semester, students periodically answered open-ended survey questions prompting them to reflect on their own and their peers' FOK. The faculty engaged in participant-observation and took notes during the joint work sessions.

Both the engineering and welding student groups were five to eight students in size, and were roughly 50% male and female in each group. Teams of approximately half welding and half engineering students worked together on a project that they mutually agreed upon. Due to the travel required for welding students to participate at the Mines campus, the engineering student more often participated in team activities, so more responses were recorded from the engineering compared to welding students.

HES graduate student results

Connecting experiences

Overall, we found gains in students' ability to draw connections between their FOK and their graduate coursework - what the survey theorizes as the construct of "connecting experiences" (Figure 2). We did not note significant differences by demographic categories.

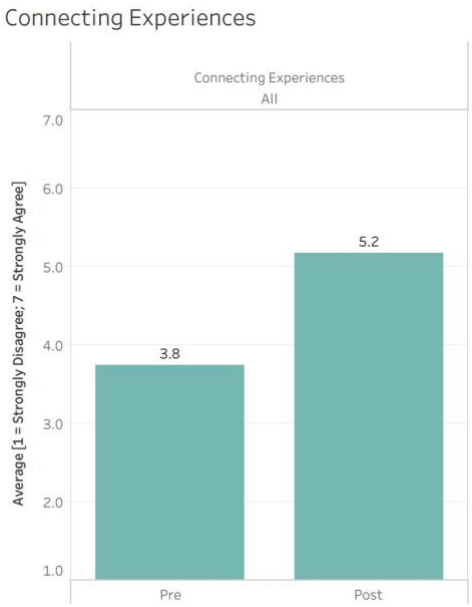


Figure 2: Comparison of pre- and post-responses to questions that make up the "connecting experiences" survey construct. In all charts, "pre" refers to student responses before attending the initial orientation, and "post" refers to their completion of the survey upon graduation.

One student narrated how his FOK being bicultural helped him in his graduate coursework. Describing his work in the restaurant industry, he recalled:

> So I knew all the food servers, and everybody at the front of the house. But since I was able to speak Spanish, I was friends with everybody on the back of the house, because a lot of them spoke Spanish. And I always made this really big effort to make sure that, I don't know, everyone felt recognized, and that…everybody understood that I was interested in conversing with everybody and making sure that everybody felt welcome.

He then connected those bicultural funds of knowledge to his graduate research, in which he conducted international research with a variety of people, from small-scale miners to managers and corporate representatives.

> My Latino background has influenced my ability to cross cultural boundaries, and interact with a variety of people from different walks of life, and how that's been instrumental in my ability to carry out my field work in this program since it's depended a lot on talking to people…. This ability that I've had since I grew up, you know, half Mexican half American, and growing up between these two worlds has really enabled me to see, be able to connect with people from, I guess, different backgrounds. And it was cool to be able to express that in front of the Multicultural Engineering Program and show that my diverse background was actually a strength instead of something that was setting me back.

Another traced her interest in sustainable infrastructure for marginalized communities to "visiting my family's hometown in Mexico, where I was able to see how the lack of basic infrastructure impacted the day-to-day lives." She saw how people were able to be creative and "make do" with what was available, including constructing their own pumps, and "that really inspired me to go into engineering." Then for her graduate research in Puerto Rico, she took a similar "sensitive and tactical approach" rather than treating them as "research subjects…getting to build those relationships and build that rapport" to elicit better information that would create more impactful research.

The increase in connecting experiences we observed in students was exciting for the team, given that prior research suggests that FOK have positive effects for students' self-efficacy beliefs, interest in engineering, and a sense of graduation certainty *if* students can draw connections between those FOK and their engineering coursework [26]. One of the specific goals of the grant is to study whether providing students opportunities to develop those connecting experiences has a positive effect for positive outcomes.

Belongingness

Overall, we found that students felt more belonging in HES, a sociotechnically-oriented graduate program, than in their more narrow undergraduate STEM programs (Figure 3). In the following charts, "field" refers to engineering and science, with distinctions at the graduate level between the engineering and science taught in their disciplinary track and the version of humanitarian engineering and science (HES) promoted by faculty and courses unique to their graduate program.

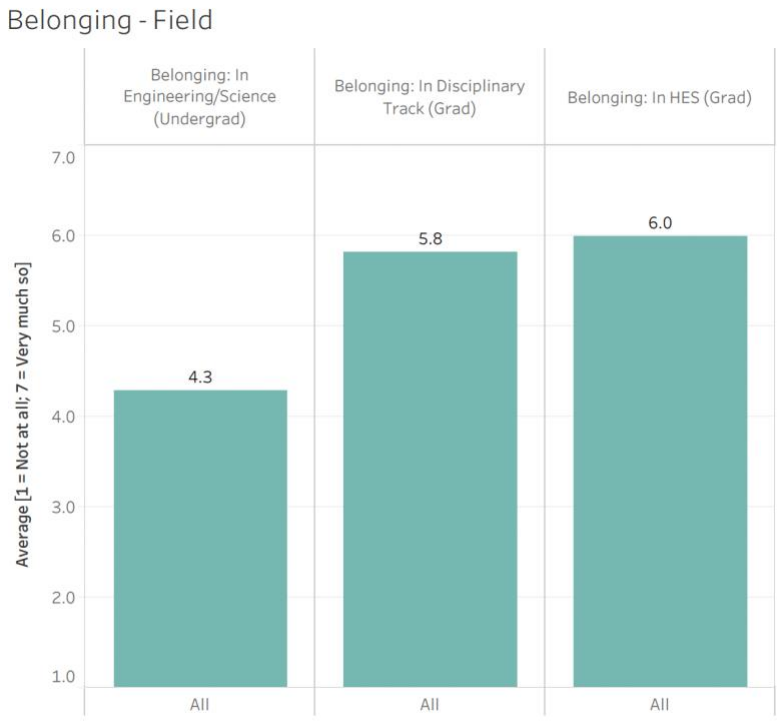


Figure 3: Average response scores for belongingness in "field" questions, all students

We did find important demographic differences. While both men and women felt greater belonging in their graduate than undergraduate major, there was a larger increase for those who identified as women (Figure 4a). One described her path to finding belonging in engineering via humanitarian themes:

> I feel like this program has made me feel more belonging within engineering. Even though in industrial engineering – maybe that's more traditional in the engineering field – but I didn't feel like I belonged as much, maybe because I had passions that were humanitarian engineering related… I didn't know that humanitarian engineering was a thing, I didn't have a name for it. So I didn't belong in that [industrial engineering] space really. But I feel like I belong more in the humanitarian engineering space. And I think humanitarian engineering is valuable to all engineering… I feel like I belong more in this program and in humanitarian engineering, because now the work that I've wanted to do seems possible, and I actually have a name for it.

Another described herself as "outside looking in" when considering her undergraduate environmental engineering major. "I belong in that space," she said, "but within myself, I feel like I don't belong. I guess that's because of the work that we're trying to do is to change engineering to be engineering as it should be and emphasize collaboration and empowerment of marginalized communities… So I feel like I belong because I've been in that space, engineering and science space, and succeeded in it, but I don't identify myself with it." In contrast, she said that when she found humanitarian engineering, "at that moment, I knew that I belonged, that was where I was meant to be. This is where I was meant to be… So my belongingness in humanitarian engineering and science is on the other side."

Those who identified as women also felt a stronger sense of belonging in their core classes (Figure 4b), which stress sociotechnical integration and are generally taught by faculty with social science PhDs. Those who identified as men felt a slightly stronger sense of belonging in their disciplinary track courses (which include environmental engineering, geophysics, and independent interdisciplinary options) than did women. Those courses also include students from those programs. We are cautious in making greater extrapolations based on our preliminary survey data, given that more people identifying as women (14) than men (9) filled out the survey.

Figure 4: Average belongingness scores by gender for (a) major and (b) classes

Additional results broken down by socioeconomic status and race and ethnicity are available in the Appendix.

Identity

The interviews were evocative for tracking the evolution of students' professional identities. Almost every single one of our students shared feeling ambivalence about pursuing engineering as an undergrad and then an "ah-ha" moment when they found a graduate program that emphasized the inherent social dimensions of engineering. One student said that he never really had a strong engineering identity because of "engineering education, culture, and what is emphasized and what's not emphasized." He described a chemical engineering unit on process safety, which was used to think about ethics. He recalled, "The opening line is, if you blow up your plant, you're not gonna make any more money… that's always been such a turnoff for me. I was not motivated by, I would say, those traditional engineering ideals of efficiency and profit." Instead, he wanted to do – or attempt to do – "ethical work, ethical projects that have impact beyond just earning a profit and making money."

Another student described how her interests in STEM and society led her to double major in geology and education as an undergraduate. "I felt like I always half belonged in science because of that duality of education and geology," she said. I have had jobs in science, I worked in a processing lab running tests, and I've also done a lot of seismic field jobs. But I always felt like something was missing. So I wouldn't say that I fully belonged in science." The graduate

program helped her finally connect her two interests together, rather than experiencing them both side-by-side. “I do feel like I belong in Humanitarian Engineering.” A classmate of hers had a similar experience. She described how proud her parents were of her by buying a bunch of engineering-themed shirts and mugs for her and themselves, but “I never identified with it” because of how technically narrow it was. She made a compromise choice for her undergraduate major, but got “excited” about STEM again once she found the graduate program. Now a working professional, she continues to live in a liminal space doing science communication. “I don’t know what’s going on, because I’m not a trained social scientist. I have done qualitative research, and I will continue to be doing qualitative research, but I don’t really consider myself a technical scientist or a social scientist.”

Another described his evolution from identifying himself as purely a technical scientist to a sociotechnical scientist. He started by saying, “I would really define myself as a technical scientist with social applications, because I really do… like the whole idea of engaging in the socio- process because you meet a lot of people that way, you find out a lot of stuff about the internal settings of an industry… to humanize the subject and bring the story into the data.” He then corrected himself putting the technical first, saying, “in the title, it starts with technical, but really it [the work and the world] starts with the social. It’d be like a sociotechnical scientist, I guess, would be a good way [to describe myself.].” He then underscored the importance of context for understanding and solving STEM problems, saying you have to think about “who can actually afford that? Where is this gonna go? That sort of thing, I don’t think, was ever discussed in any of our engineering courses. Even in our engineering courses we had to develop small machines, using pieces and codes and stuff like that, but I don’t think we ever talked about, well, how would somebody use this?” He continued, “Every project is situational, and it's not always apparent. And what humanitarian engineering does that's different from regular engineering is that it uses some of the social, technical, and qualitative applications to just start to find problems that can influence your technical design or implementation.” He concluded, “So I guess, thinking about my place in engineering, I was always thinking about more of the technical approach of engineering application. But through my [graduate] experience… I’ve realized that there is this gap in understanding engineering application and communication, and there’s a missing piece… let’s bring trust back into engineering and application by using these themes of [humanitarian engineering and science].”

We also tracked the evolution of STEM identity using the survey. The survey follows [9], [29] in theorizing STEM role identity as a combination of recognition as a scientist or engineer (both internal – “I see myself as a scientist/engineer” – and external – “Others see me as a scientist/engineer”); interest in science or engineering; and competence beliefs. We found that students overall saw increases in being externally recognized as an engineer/scientist and in their senses of competence as engineers or scientists. Their interest in engineering and science actually decreased (Figure 5). The largest jumps we observed in internal recognition were for students who identified as women (yellow bars), as Hispanic/Latino (purple bars), and as Pell students (red bars). Scores for internal recognition actually decreased for the other students (Figure 5).

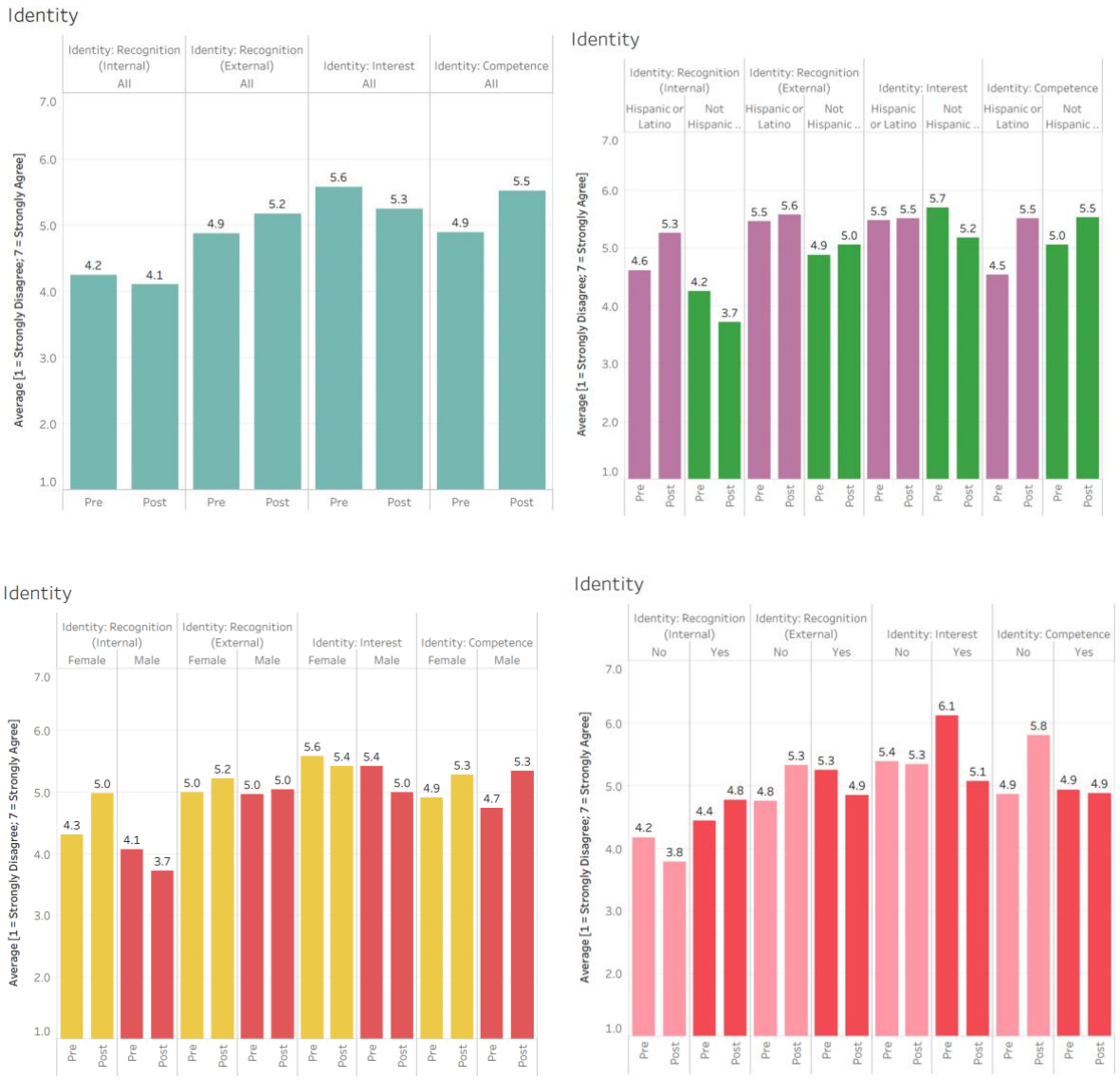


Figure 5: Pre and post identity scores, clockwise from upper left: all students, ethnicity, scholarship status, and gender.

Challenging dominant engineering epistemologies

For all of these students, establishing their own belonging in science and engineering hinged on them redefining science and engineering to encompass the social. The importance they placed on the social is likely what led to their senses of alienation as undergraduates in more traditional science and engineering majors and their greater feelings of belongingness in their sociotechnically integrated graduate program. By insisting on the inherent social dimensions of science and engineering, they challenged the technical/social dualism that would otherwise define the social as external to – and less important than – the technical [30].

Most of our students traced their ambiguous belonging in STEM all the way back to their undergraduate experiences, when they knew something was missing. The graduate program

provided the conceptual frameworks and language to articulate what exactly was missing and what was problematic with mainstream STEM. One student passionately described how the program crystallized his discomfort with the concept of scientific objectivity. He started by saying that the program "shattered" the myth of objectivity, but then clarified that "I was already a pretty skeptical person, but [the program] gave me more, a deeper understanding of how mythical the myth of objectivity is." He continued:

> As I've learned more about how knowledge is produced through this program, I've realized how political it is and how… there's so many elements where humans are involved and that changes… the results of what we perceive to be as objective fact. Especially in the larger public, in so many news articles, and in so many conversations I've had with people about peer-reviewed studies, [it's as if] they're the word of God. They are definitely better than just asserting something without evidence, but at the same time, there's so many factors that influence the results of these studies. Even in the most scientific, technical world, like something that's just numbers, there's still so much politics behind that, there's still so much room for people's biases to be ingrained into that. And also, it's not just personal biases, too, it's systemic issues that give some people more power than others. Those are baked into the results of science and scientific projects, and those manifest in engineering projects, too, and engineering is what the construction of our society depends on. So I found a clear line between these biases, systemic imbalances of power, and how that's translated into the built structures that we live our lives through.

This critical stance led many of our students to embrace intellectual humility in the face of STEM ways of being that emphasized infallible expertise. This stance was evident in the student above, who recognized that doing qualitative research did not make her a social scientist. Another student said she wasn't sure how she identified herself. "I would like to call myself a humanitarian engineer, since that's what I want to do. This program was perfect for me. It's what I've always wanted to learn." She continued, "I want to call myself that, but I also feel like I still have so much more to learn before I could call myself that, and I need more experience doing humanitarian engineering work. So I'm not really sure. I have training in industrial engineering, but I don't know if I would call myself an industrial engineer anymore, since I haven't worked at an industrial engineering job for a while." She paused and concluded, "So, an aspiring humanitarian engineer. Maybe."

The students' growing skepticism also seems to have changed their views of the power of science and engineering to address challenges and solve problems. Average responses to the questions tracking the efficacy of science and engineering went slightly down for all students, but especially for those who received an S-STEM scholarship (Figure 6). While scholarship status does not uncritically reflect the socioeconomic status of the households that the students grew up in, as described above, it is possible that their greater financial precarity made them more skeptical of the power of science and engineering to solve systemic problems such as poverty.

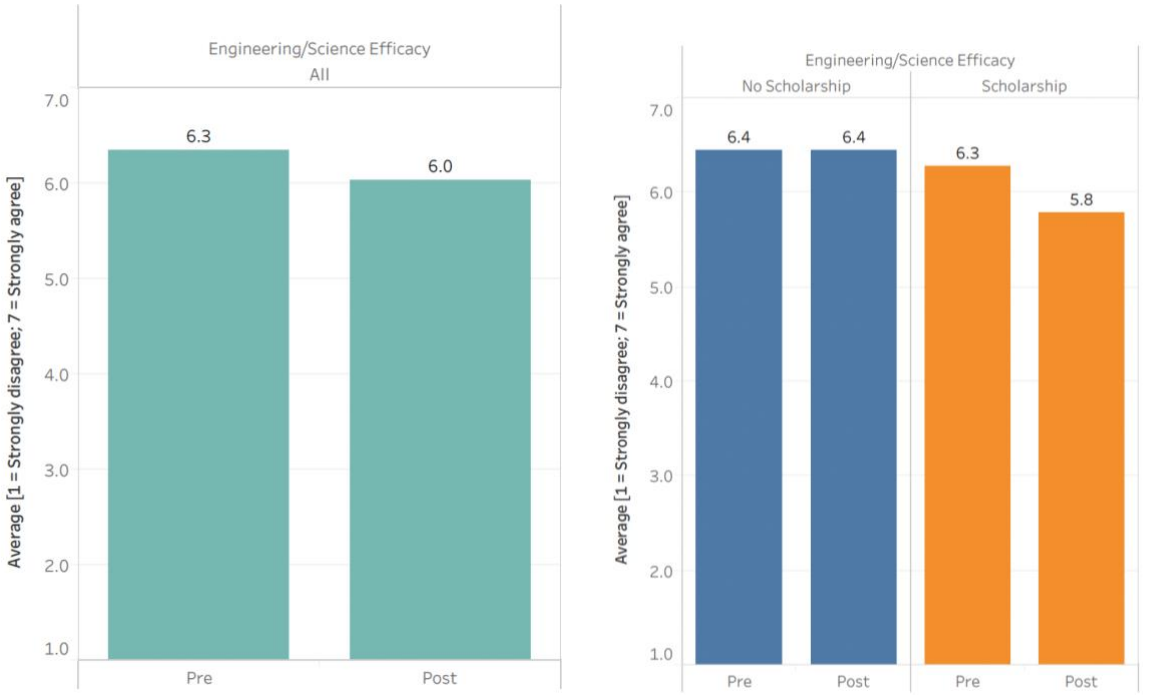


Figure 6: Pre- and post- engineering efficacy scores for all students (a) and scholarship status (b)

MME and welding students' results

The focus of our efforts in this project was to foster mutual respect between students at a four-year engineering university and a two-year community college. In his own prior work as a welder, Klemm-Toole had observed firsthand tensions between engineers and welders and wanted his own engineering students to be more respectful of the knowledge held by people from the skilled trades. One of the greatest challenges in cultivating mutual respect is the evolution of US engineering education over the past century, which has widened the chasm between engineers and technicians. These tensions have a historical basis in efforts to establish engineering as a *profession* distinct from blue-collar labor [31], [32]. The first engineers came from the ranks of skilled mechanics, meaning that they shared a "common occupational culture and training" with workers [33]. This changed with the creation of a bifurcated educational system that credentialed engineers in four-year programs emphasizing math and science while channeling technicians into "practical" two-year community college programs.

Because the FOK approach is one based in recognizing assets from diverse backgrounds, we thought it was particularly promising to frame the interactions between the two groups of students. The FOK activity – including the share-out of the students' maps – made visible overlaps between the two groups of students, such as enjoying outdoor activities and working with their hands. However, it also made differences visible. In one of the classes, for example, only one MME student mentioned FOK from a job, whereas all of the community college students did.

Our data offers preliminary evidence both for engineering students' own professional development and for their growing appreciation of team members with different educational backgrounds. Students articulated an increased understanding of their own FOK. For example, one stated that "there are both technical and soft skills that I have developed in other areas of my life that are relevant to my career." A few students similarly compartmentalized their FOK into technical and social domains. For example, one wrote, "I think work in the physical sciences limits the impact of sociologically based funds of knowledge and that is the great equalizer in STEM. There is no 'you know something differently', either you do or don't. Funds of knowledge are impactful for doing everything that isn't the physical science, IE: organizing, communicating, and developing brainstorms to fruitful deliverables....etc." This student's comments drew a clear boundary around engineering knowledge.

Others took a less compartmentalized approach, such as one student who stated, "I learned that no part of me is isolated from the other." Another realized that "I have a wider variety of knowledge…and they are more applicable than I thought." Another student said:

> I think that a lot of engineers get caught up in the pride of fully 'owning' a project and struggle to ask for help when running into a problem that they do not know how to solve...my background in team sports has given me a lot of time working within a team and also working under someone that you may not necessarily agree with or get along with. I like to think that I can work for anyone and with anyone after my time playing football at Mines.

Students also identified ways that their peers' FOK contributed to the success of the capstone project. One of the welding students both appreciated the potential for the robotic welder to make their work more efficient and came to see that "everyone sees things differently and everyone can bring a good idea to the table." An MME student emphasized commonality, writing, "Communication between engineers and technicians can be challenging but shouldn't. We seem to have more in common with each other than not and are working towards common goals just from different points of view/contributions." Another student similarly emphasized the practical value of learning to appreciate others' FOK: "It is important to connect with people and learn about their knowledge. It will allow you to connect with them better and give you opportunities to learn more and see situations from new perspectives. This can help you solve problems." In a class debrief, they shared the importance of not "getting caught up in ego," saying that people with different education can make big contributions to problem solving. In another debrief, the MME students decentered the importance of their own training by stating that the welders "could have completely done the project by themselves" and that if it had just been them, they would not have been as productive right off the bat. Another half-joked in a survey response, stating, "I learned that it's good I decided to do engineering because I have very few useful skills."

An engineering student stated, “I saw the welders take very direct approaches to the project here which was refreshing from an engineering perspective where problems can sometimes be made too complicated.” Another remembered how one of the welding students “MIG welded a rod to a base plate manually, and like it was nothing. It was super cool to watch them show off something they’d clearly been practicing.” Another complemented the welding students for being “able to recognize and adapt parameters based on the weld result.” We watched one MME student appreciate the knowledge brought by one of the welders. The MME student had drawn an intricate design for their proposed group welding project on the board and explained a few different theories at length about how it would work. When she was ready for questions, the welder diplomatically said the design wouldn’t work because of a combination of gravity, the speed at which the material would harden, and the necessary placement of the body to achieve the welds. The MME student sunk her shoulders but smiled, chuckling as she erased the design from the board.

Based on weekly observation of the groups of engineering and welding students, it was clear that each group felt more comfortable with a particular set of tasks and focused on those at the beginning of the project. Being generally comfortable with operating welding equipment by hand, the welding students focused on setting up the welding robot with the correct wire feedstock, setting shielding gas flow rates, and adjusting welding parameters. The engineering students initially focused more on fixturing base base plates together and programming the robot. Throughout the course of the semester, the engineers and welders gradually aligned in the tasks they performed, and by the culmination of the project, there was no clear delineation in the task being performed by a given individual based on their educational background. By the end of the project, the engineers and welders had formed a cohesive and effective problem solving team with clear demonstrations of mutual respect.

While we did not ask specific questions about belonging, the welding students’ survey responses suggest that they became more confident in their abilities to use the robotic welder and collaborate with the engineering students. Most of the engineering students developed appreciation for the welding students’ unique knowledge, as well as their own. A few did cordon off “non-technical” knowledge as not being relevant to engineering. The more mixed results we experienced in this project are likely due to the different nature of the course and project. The HES program draws students who are already skeptical of dominant and exclusionary engineering epistemologies, whereas the MME students are enrolled in a more traditional curriculum. In future versions of the project, it would be valuable to investigate if there are patterns (demographic and otherwise) among the MME students in terms of which were more likely to compartmentalize “valuable” FOK.

Conclusion

Both FOK-themed educational interventions questioned mainstream engineering epistemologies. The HES graduate program critiques the social/technical dualism that constitutes the majority of engineering practice and education and opens up crucial questions about who engineering benefits and harms. Whereas mainstream engineering education has devalued practical knowledge, the welding project encouraged the engineering students to appreciate the knowledge held by the welding students and take a more humble approach to their own. In opening up dominant definitions of engineering, we hoped to provide more opportunities for students from diverse backgrounds to see themselves in engineering.

This paper did not start with the presumption that senses of belonging in engineering are necessarily good or desired. Instead, we showed how questioning traditional engineering itself – by providing an academic space for students to wrestle with their ambiguous relationships with engineering and by celebrating technoskeptical thinking – can support minoritized students' internal recognition as engineers. In fact, technoskeptical thinking itself can be viewed as a valuable fund of knowledge [34]. The HES graduate program shows the clearest evidence for this questioning enhancing minoritized students' belongingness. All students felt a greater belongingness in their graduate rather than undergraduate program. While in graduate school, students who identified as women and those who had received Pell and our scholarship felt much greater belonging in the sociotechnically-themed courses rather than their disciplinary track courses, which were more technically narrow. Students who identified as women, as Hispanic or Latino, and as Pell students saw the greatest jumps in internally recognizing themselves as engineers. Their senses of external recognition, however, were flat. This raises an intriguing predicament that merits further investigation. Sociotechnically-grounded STEM education may provide a way for students from minoritized backgrounds to *internally* identify with STEM, but redefining STEM to be less technically narrow may simultaneously erode their *external* recognition as STEM professionals because they do not fit inside of a predictable box. We thus provide further evidence that broadening participation in engineering will ultimately depend on redefining engineering itself, rather than expecting minoritized students to uncritically identify with a field with so many ethical failures.

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Appendix

Belongingness and ethnicity: We found that students who identified as Hispanic or Latino (five of our 23 students) felt slightly greater belonging than their peers in both their graduate disciplinary field and the more sociotechnical humanitarian engineering and science field (Figure 7).

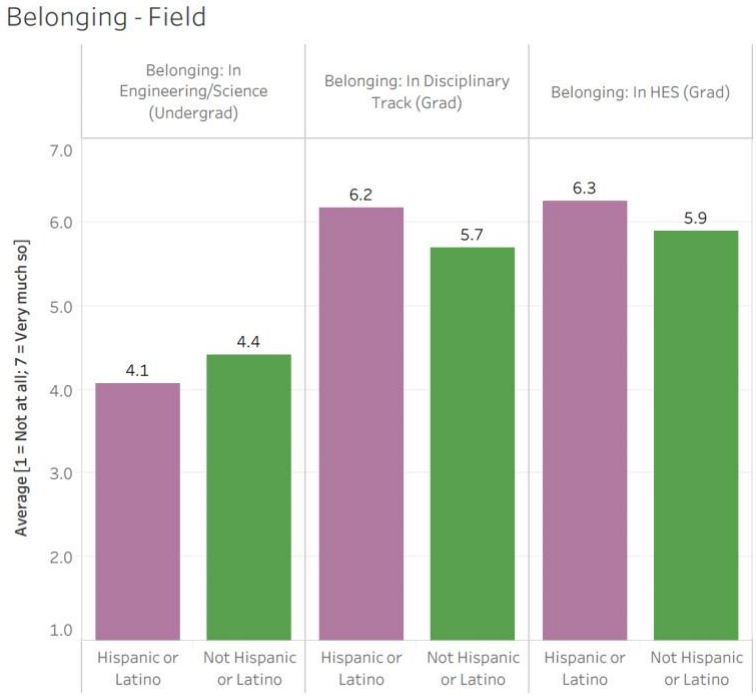
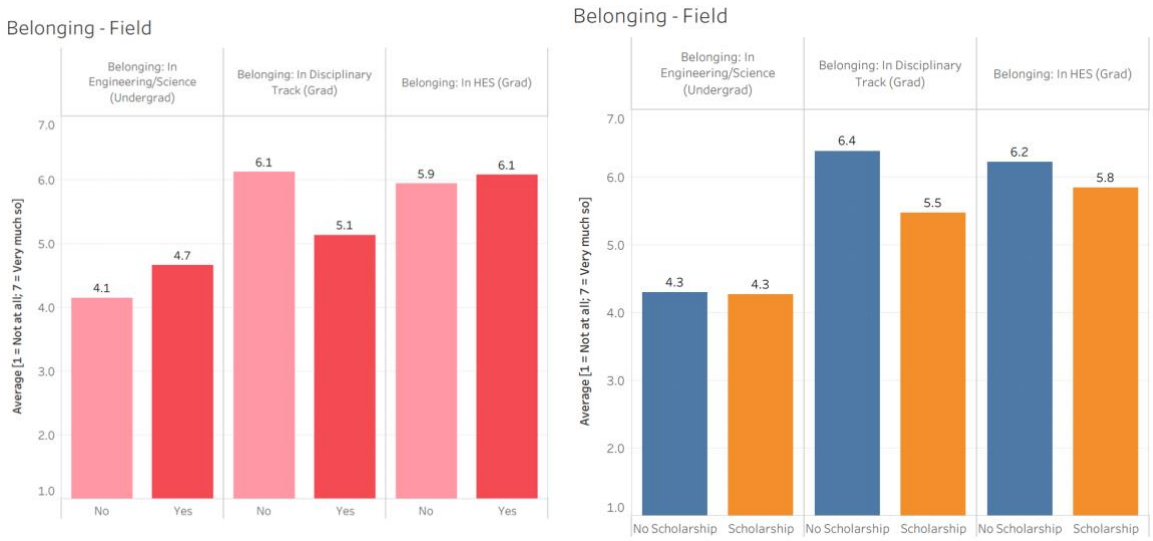


Figure 7: Average field belongingness scores, by ethnicity

Belongingness and socioeconomic status: We found that Pell recipients (dark red bars in Figure 8a) and scholarship recipients (orange bars in Figure 8b) felt more belonging in their graduate than undergraduate program (and at higher rates than their peers), but that they felt less belonging in their STEM-based disciplinary track than their peers.



: Average field belongingness scores, by (a) Pell status (red/pink) and (b)scholarship status (blue/orange)

Belongingness in social relationships (all HES students): Whereas the above survey responses refer to students' senses of belonging in their field, major, and courses, the survey also specifically tracked students' sense of belonging in social relationships associated with the undergraduate and graduate programs. We found an overall increase in this sense of belonging (Figure 9). We did not find significant differences by gender.

Figure 9: Average response scores for belonging in social relationships questions, all students

Belongingness and socioeconomic status: Scholarship and Pell recipients, however, felt less belonging in social relations in both their undergraduate and graduate school experiences than their peers, though their scores nonetheless increased (Figure 10).

Figure 10: Average belonging in social relationships scores by (a) Pell status (red/pink) and (b) scholarship status (blue/orange)

STEM identity and socioeconomic status: We also found that scholarship students did not see the same gains in competence scores and external recognition that non-scholarship students saw:

Figure 11: Pre and post identity scores by scholarship status

References

[1] E. A. Cech, "The intersectional privilege of white able-bodied heterosexual men in STEM," *Sci. Adv.*, vol. 8, no. 24, p. eabo1558, Jun. 2022, doi: 10.1126/sciadv.abo1558.

[2] M. Polmear, N. J. Hunsu, D. R. Simmons, O. P. Olaogun, and L. Lu, "Belonging in engineering: Exploring the predictive relevance of social interaction and individual factors on undergraduate students' belonging in engineering," *J. Eng. Educ.*, vol. 113, no. 3, pp. 555–575, 2024, doi: 10.1002/jee.20599.

[3] A. Patrick, M. Andrews, C. Riegle-Crumb, M. R. Kendall, J. Bachman, and V. Subbian, "Sense of belonging in engineering and identity centrality among undergraduate students at Hispanic-Serving Institutions," *J. Eng. Educ.*, vol. 112, no. 2, pp. 316–336, Apr. 2023, doi: 10.1002/jee.20510.

[4] S. Hug and S. Eyerman, "Applying an Integrative Belonging Framework to Explore Students' Perspectives at HSIs," in *2024 ASEE Annual Conference & Exposition Proceedings*, Portland, Oregon: ASEE Conferences, Jun. 2024, p. 46590. doi: 10.18260/1-2--46590.

[5] D. Verdín, P. University, and W. Lafayette, "Understanding How Engineering Identity and Belongingness Predict Grit for First-Generation College Students," p. 17.

[6] A. Rainey, D. Verdín, and J. M. Smith, "Classroom Practices that Support Minoritized Engineering Students' Sense of Belonging," presented at the American Society for Engineering Education, 2021.

[7] C. E. Foor, S. E. Walden, and D. A. Trytten, "' I Wish that I Belonged More in this Whole Engineering Group:' Achieving Individual Diversity," *J. Eng. Educ.-Wash.-*, vol. 96, no. 2, p. 103, 2007, Accessed: Nov. 29, 2012. [Online]. Available: https://asee.org/2007/april/4.pdf

[8] J. M. Smith and J. C. Lucena, "Invisible innovators: how low-income, first-generation students use their funds of knowledge to belong in engineering," *Eng. Stud.*, vol. 8, no. 1, pp. 1–26, Jan. 2016, doi: 10.1080/19378629.2016.1155593.

[9] D. Verdín, J. M. Smith, and J. C. Lucena, "First-generation college students' funds of knowledge support the development of an engineering role identity," *J. Eng. Educ.*, vol. 113, no. 2, pp. 383–406, 2024, doi: 10.1002/jee.20591.

[10] D. Riley, "Engineering and Social Justice," *Synth. Lect. Eng. Technol. Soc.*, vol. 3, no. 1, pp. 1–152, Jan. 2008, doi: 10.2200/S00117ED1V01Y200805ETS007.

[11] J. A. Leydens and J. C. Lucena, *Engineering Justice: Transforming Engineering Education and Practice*, 1 edition. Wiley-IEEE Press, 2017.

[12] E. Blue, M. Levine, and D. Nieusma, *Engineering and War: Militarism, Ethics, Institutions, Alternatives*, 1st edition. San Rafael, California: Morgan & Claypool Publishers, 2013.

[13] S. Mitra, S. Sarkar, and A. Ganguli-Mitra, "On the need for an anticolonial perspective in engineering education and practice," *Nat. Commun.*, vol. 14, no. 1, p. 8453, Dec. 2023, doi: 10.1038/s41467-023-43952-2.

[14] J. Valle, A. Slaton, and D. Riley, "A Third University is Possible? A Collaborative Inquiry within Engineering Education," presented at the 2022 ASEE Annual Conference & Exposition, Aug. 2022. Accessed: Jan. 11, 2025. [Online]. Available: https://peer.asee.org/a-third-university-is-possible-a-collaborative-inquiry-within-engineering-education

[15] A. Slaton and S. Vakil, "Engineering Education in Times of War, Upheaval, and Revolution," in *2024 ASEE Annual Conference & Exposition Proceedings*, Portland,

Oregon: ASEE Conferences, Jun. 2024, p. 47280. doi: 10.18260/1-2--47280.
[16] J. Holly, "Disentangling engineering education research's anti-Blackness," 2020, Accessed: Dec. 27, 2024. [Online]. Available: https://deepblue.lib.umich.edu/bitstream/handle/2027.42/191175/Holly%20Jr%20%282020%29_Disentangling%20engineering%20education%20researchs%20anti-Blackness.pdf?sequence=2
[17] D. Parnell, J. Wilson, K. Hicklin, and J. Waisome, "Engineering While Black: Exploring the Experiences of Black University of Florida Undergraduate Engineering Students Using Photovoice," in *2023 ASEE Annual Conference & Exposition Proceedings*, Baltimore , Maryland: ASEE Conferences, Jun. 2023, p. 43351. doi: 10.18260/1-2--43351.
[18] A. Pawley, J. Mejia, and R. Revelo, "Translating Theory on Color-blind Racism to an Engineering Education Context: Illustrations from the Field of Engineering Education," in *2018 ASEE Annual Conference & Exposition Proceedings*, Salt Lake City, Utah: ASEE Conferences, Jun. 2018, p. 31161. doi: 10.18260/1-2--31161.
[19] J. A. Henderson, B. L. McGowan, J. Wawire, L. S. S. Benjamin, K. L. Schaefer, and J. D. Alarcón, "Photovoice: Visualizing the engineering identity experiences of sophomore students," *J. Eng. Educ.*, vol. 112, no. 4, pp. 1145–1166, Oct. 2023, doi: 10.1002/jee.20555.
[20] E. Bonilla-Silva, *Racism without Racists: Color-Blind Racism and the Persistence of Racial Inequality in America*, Fifth edition. Lanham: Rowman & Littlefield Publishers, 2017.
[21] M. A. Beasley, *Opting Out: Losing the Potential of America's Young Black Elite*, Illustrated edition. Chicago: University of Chicago Press, 2011.
[22] L. Martin and K. Wendell, "Reflections on Asset-Based Pre-College Engineering Education to Promote Equity: An Introduction to the Special Issue," *J. Pre-Coll. Eng. Educ. Res. J-PEER*, vol. 11, no. 1, May 2021, doi: 10.7771/2157-9288.1325.
[23] L. C. Moll, C. Amanti, D. Neff, and N. Gonzalez, "Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms," *Theory Pract.*, vol. 31, no. 2, pp. 132–141, Mar. 1992, doi: 10.1080/00405849209543534.
[24] M. Esteban-Guitart, E. Iglesias, J. M. Serra, and D. Subero, "Community Funds of Knowledge and Identity: A Mesogenetic Approach to Education," *Anthropol. Educ. Q.*, vol. 54, no. 3, pp. 307–317, 2023, doi: 10.1111/aeq.12451.
[25] N. Gonzalez, L. C. Moll, and C. Amanti, Eds., *Funds of Knowledge: Theorizing Practices in Households, Communities, and Classrooms*, 1st edition. Mahwah, N.J: Routledge, 2005.
[26] T. J. Yosso *, "Whose culture has capital? A critical race theory discussion of community cultural wealth," *Race Ethn. Educ.*, vol. 8, no. 1, pp. 69–91, Mar. 2005, doi: 10.1080/1361332052000341006.
[27] J. Pleasants, "Engineering for Whom? Investigating How Engineering Students Develop and Apply Technoskeptical Thinking," *Eng. Stud.*, vol. 16, no. 3, pp. 159–183, Sep. 2024, doi: 10.1080/19378629.2024.2333242.
[28] D. Verdín, J. M. Smith, and J. C. Lucena, "Recognizing the funds of knowledge of first-generation college students in engineering: An instrument development," *J. Eng. Educ.*, vol. 110, no. 3, pp. 671–699, 2021, doi: 10.1002/jee.20410.
[29] D. Verdín, A. Godwin, and M. Ross, "STEM Roles: How Students' Ontological Perspectives Facilitate STEM Identities," *J. Pre-Coll. Eng. Educ. Res. J-PEER*, vol. 8, no. 2, Nov. 2018, doi: 10.7771/2157-9288.1167.
[30] 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: Critical Explorations and Opportunities, J. Lucena, Ed., in Philosophy of Engineering and Technology. , Dordrecht: Springer Netherlands, 2013, pp. 67–84. doi: 10.1007/978-94-007-6350-0_4.

[31] T. S. Reynolds, Ed., *The Engineer in America: A Historical Anthology from Technology and Culture*, 1 edition. Chicago: University of Chicago Press Journals, 1991.

[32] J. S. Rolston and E. Cox, "Engineering by Doing: Diversity, Innovation and Hands-On Learning," in *Engineering in Context: International Perspectives on Engineering Education*, Springer, 2015.

[33] R. Zussman, *Mechanics of the Middle Class: Work and Politics Among American Engineers*. University of California Press, 1985.

[34] J. Smith and J. Lucena, "'How do I show them I'm more than a person who can lift heavy things?' The Funds of Knowledge of Low Income, First Generation Engineering Students," *J. Women Minor. Sci. Eng.*, vol. 22, no. 3, pp. 199–221, 2016, Accessed: Jan. 29, 2017. [Online]. Available: http://www.dl.begellhouse.com/journals/00551c876cc2f027,5edce44f714d0923,01d8789e0fece011.html