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Developing Engineers' Critical Consciousness through Gender and Ethnic Studies: Reframing STEM Identity

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Abstract

Brazilian educator Paolo Friere's influential notion of "critical consciousness" [1] requires that subjects become aware of the complex systems of power and oppression in which they are enmeshed and develop a sense of social justice that leads them to take liberatory action. We investigate the question of whether coursework in women's, gender and sexuality studies (WGSS) or ethnic studies empowers minoritized engineering students to develop critical consciousness relative to the culture of engineering. Our work investigates the influence of two such courses on student attitudes and motivation by gathering both qualitative and quantitative data from students in two STEM-themed courses in WGSS and ethnic studies, "Gender and STEM" and "Race and Technology." We argue that in these courses students acquire skills that enable them to critically reflect on both the socially constructed nature of STEM and on the historical patterns within engineering culture that exacerbate existing inequities and injustice despite claims of "neutral" objectivity. In preliminary data, students report that these critical lenses on engineering are vision-clarifying and -broadening (reflecting the core concept of "meta-cognition" that underpins critical consciousness), and also motivate them to persist in and transform the culture of engineering (reflecting critical consciousness' core value of movement toward justice-oriented action). As students develop a critical consciousness relative to engineering culture through their engagement with this coursework, their responses to instruments measuring "engineering identity" highlight and reveal the more specific ways in which this consciousness has developed. Our findings highlight the tremendous curricular power of interdisciplinary coursework and learning experiences that help engineering students develop critical consciousness within and about the culture of engineering.

Introduction

Critical consciousness in the context of Women's, Gender & Sexuality Studies and Ethnic Studies

Our previous work has qualitatively investigated how STEM-themed coursework in Women's, Gender, & Sexuality Studies (WGS) influenced the attitudes, perspectives, and identity formation of marginalized engineering students [2]. Such students reported finding this coursework to be empowering, liberatory, and strengthening of their STEM confidence and preparedness. They pointed to their acquisition of a critical lens on STEM's claimed "objectivity," and the move from an individualized to a systemic understanding of the culture of STEM, as key to these influences.

These findings suggest that gender studies coursework focused on STEM may function as the kind of “culturally relevant pedagogy” that can strengthen STEM students’ critical consciousness [3]. Our prior findings, coupled with both our sense of the synergy between both WGS and ethnic studies coursework and also the idea of critical consciousness, have led us to further investigate the influences of two STEM-themed courses on student attitudes and mindsets.

Critical consciousness (CC) was conceptualized by Paulo Friere as a framework for those oppressed within systems of power and privilege to “read the world,” think critically about inequitable conditions, and take action to change those conditions [1]. Friere noted the importance of both seeing and understanding one’s sociopolitical context and feeling agency within it, characterizing critical consciousness as “reflection and action upon the world in order to transform it” [4] Critical pedagogy [5] has explored the potential of education and praxis to develop such knowledge and transformation.

Friere proposed an educational model in which a person came to understand themself and their situation by “problematiz[ing] the natural, cultural and historical reality in which [they are] immersed” [4]. Problematization of one’s lived environment involves asking questions about aspects that may generally be taken for granted, disrupting common assumptions, and suggesting the existence of alternatives. This capacity, “critical consciousness,” is distinct from the common “problem-solving stance” [4] that is characteristic of, normatively, engineering students. Problematizing the assumptions behind “reality” and engaging in problem-posing, rather than problem-solving, can encourage students to explore new perspectives and discover new approaches, rather than passively receiving knowledge within fixed and limiting frameworks. It positions students as potential knowledge makers and action-takers who are unlimited by the unarticulated assumptions of any given system.

The strong association between knowledge and transformative action resonates powerfully with the historical development of interdisciplinary fields such as WGS and ethnic studies, two areas of study that similarly emphasize interrogating systems of unjust power and identity hierarchies, questioning ideological assumptions, and linking critical thought and social change. Connecting liberatory ideas with transformative action is a shared premise behind WGS, ethnic studies, *and* critical consciousness. Black feminist scholar bell hooks [6] has specifically connected Friere’s framework to intersectional contemporary feminism and anti-racism, positing that disrupting classroom power structures in terms of gender and race would powerfully lead toward such reflective action. While the analyses of Mustakova-Possardt [7] suggest that “CC may not be the automatic outcome of the development of systemic thought and its application to understanding social reality,” both WGS and ethnic studies consistently involve pedagogies that complement the development of critical consciousness, “where students (a) gain sociopolitical understanding, or engage in critical reflection, to (b) change the world, or take critical action” [8].

An analytical review of CC literature by Jemal [9] observes divergence in the interpretation of “critical action,” with some scholars viewing the capacity, or the intention, to take action, as sufficient, and also divergence in whether and how critical consciousness may be experienced by the privileged as well as the oppressed. Jemal proposes the notion of “transformative potential” to clarify the construct of critical consciousness on both counts.

Engineering identity and critical consciousness

While the engaged presence of diverse perspectives in engineering education is understood to be inherently valuable, institutions continue to inadequately center the inclusion, retention, and thriving of engineering students from historically minoritized groups. The intentional development of critical consciousness in engineering students may be one important tool for advancing this greater project. Holly [10] proposes that "CC presents itself as a useful concept to better understand why these efforts have not been successful in transforming the quality of experiences and statistical representation of people [from] groups that have been marginalized in engineering throughout history." The elusive goal of "broadening participation in engineering" may in fact be strongly supported by the development of critical consciousness about and within the culture of engineering.

Donna Riley has long advocated for Friere's liberatory pedagogies to be integrated into engineering education [e.g. 11], and has made the case that feminist and antiracist theory is particularly relevant in reorienting engineers toward thoughtful problem-posing and toward an ethic of care [12]. Problematizing the norms of engineering education would involve a pedagogy of resistance: to "identify and then challenge epistemic assumptions that make engineering unjust," and then to "act effectively in response" as empowered "learners, questioners, and actors" [13].

While there are measures for critical consciousness, including formal scales such as those developed by Thomas et al [14] and Diemer et al [15], this project tracks the development of critical consciousness via shifts in engineering students' perceptions of their STEM identities. There are several reasons for this choice. The literature on STEM diversity strongly suggests that a robust "STEM identity" can be a critical element of STEM student persistence. In particular, the research on STEM identity emphasizes the importance of students' active and intentional engagement with the powerful but frequently masked sociocultural contexts of STEM, especially relative to STEM fields' long histories of implicit and explicit bias in terms of gender, race and other aspects of identity. Carlone [16,17] has argued that examining STEM identity formation can offer new ways to understand the process of enculturation into the community of scientific practice, and make science education more equitable by acknowledging the social construction of science and helping students recognize their own agency. Tonso [18] described engineering identity development as "a complicated process through which campus engineer identities [...] provide a lens of meaning through which to 'recognize' (or not) performances of engineer selves as engineers." Choe et al. [19] identified engineering practice factors such as tinkering, design, framing and solving problems, and collaboration, and found that students who had positive views of these factors also had stronger engineering identities. Claussen et al [20] acknowledge the intersectional and transitional nature of "liminal" engineering identity formation for students, and offer ways to understand that liminality. And while STEM identity itself is not a monolithic concept, it is possible to identify patterns that indicate various "types" of science identities [21]. When seen in the context of this research, STEM identity offers a promising lens through which to view student development of a meta-cognitive perspective on engineering and a reflective approach to understanding engineering as a culturally-bound and changeable set of world views and practices. In short, it offers a way to glimpse the development of critical consciousness.

In addition to qualitative work characterizing STEM identity development, some research has focused on quantitatively measuring STEM identity. Such measures tend to assess either the centrality or the typicality of participants' STEM identities. Acknowledging that both self-assessment and recognition by others as a doer-of-STEM are critical aspects of STEM identity development, McDonald et al [22] developed and tested a single-item measure the extent to which students perceive they "fit" within what they consider to be a professional STEM identity. This measure allows for a student-centered approach to gathering data around how STEM identity may be impacted by course content and the student learning experience.

This current work looks to further our understanding of how the critical frameworks, interdisciplinary methods, and conceptual vocabulary associated with gender and ethnic studies courses can positively influence engineering identity formation, in part by expanding and complicating students' understanding of "engineering identity" itself. This move from learning to see and acknowledge systemic biases to working towards dismantling them—"from persistence to resistance," as Riley and Claris [13] put it—is reflective of meta-cognitive shifts and impetus toward liberatory actions that signal how certain educational experiences can enable the emergence of critical consciousness.

Institutional and Course Context

We focused our study on two classes we teach at our institution, a liberal arts college that offers six degree programs in engineering. As courses associated with interdisciplinary programs at Lafayette College, these classes have content and structure that speak to Riley's call for interdisciplinary partnership in bridging engineering, gender studies, and ethnic studies [12]. One class, WGS 250 Gender & STEM, developed and taught by the second co-author for the Women, Gender, & Sexuality Studies program, has been previously studied [2,23]; the second, cross-listed in Africana Studies and Engineering Studies and developed and taught by the first co-author, focuses on Race & Technology. The course descriptions and learning outcomes for each class follow:

> ***WGS 250: Gender and STEM*** explores the relationship between gender and STEM fields. It examines how stratified social systems— principally organized around gender and gender identity, and also race/ethnicity and sexual identity—intersect with STEM-related areas of inquiry. Using a variety of interdisciplinary perspectives, WGS 250 investigates how STEM fields *both shape and are shaped by* ideas and assumptions about gender and identity. Topics include feminist critiques of science, intersections of gender with technology design/use, gender and the built environment, and links between gender and "doing" STEM.
>
> Learning Outcomes:
> - Demonstrate an understanding of core critical concepts in the field(s) of feminist STEM studies, particularly critiques of *objectivity*, *neutrality*, and *evidence*.
> - Identify and articulate the mutually constitutive intersections of social categories (particularly gender, race, and sexual identity) and STEM fields.
> - Think critically about the role of power and politics in the shaping of scientific thought, facts, and practices.
> - Articulate and explain the differences and links between critiques of STEM content and critiques of STEM field participation.

- Understand the social significance of at least two dimensions of identity and/or difference (e.g., gender, race, ethnicity, class, sexuality, religion, etc.) that exist (or have historically existed) in hierarchical relation to each other. [supports common curricular requirement]

AFS/EGRS 220: Race & Technology provides an introduction to the many ways in which science, technology, and race are constructed and construct each other. How do technologies express ethno-racial and gender politics reflected elsewhere in society? How do race and ethnicity shape technologies, technical design, and technology policies? We will examine how medical technologies, infrastructure, workplaces, and digital media platforms continue to reinscribe – and occasionally reinvent – racial categories and hierarchies. We will also explore counterexamples, including feminist and anti-racist thinkers and labs repurposing oppressive tools for liberatory applications.

Learning Outcomes:

- Demonstrate an understanding of the historical and contemporary construction and performance of race through technology.
- Articulate and explain the interrelation of race, ethnicity, and technology.
- Examine how power, identity, and politics shape the development of new scientific facts and technical artifacts.
- Think critically about issues of race in new media technologies.
- Understand the social significance of at least two dimensions of identity and/or difference (e.g., gender, race, ethnicity, class, sexuality, religion, etc.) that exist (or have historically existed) in hierarchical relation to each other. [supports common curricular requirement]

As the course descriptions show, these courses are designed to demonstrate that science and technology, like race and gender, are social constructs, and to investigate the ways technological processes, practices, and products reflect gender and racial biases. These classes ask students to read and discuss a wide range of scholarship, and to reflect on their own gender and racial identities and experiences—much as Mejia et al found effective in developing sociotechnical thinking [24]. For example, assignments in Gender and STEM ask students to reflect on and analyze their own (pre-College) living space in terms of its gendered/racialized features (per Wacjman's analysis of politicized built environments) and to locate and analyze popular press articles on "the science of sex differences" relative to their assumptions about gender and the gender binary (per Caroline Perez and Cordelia Fine). Assignments in Race & Technology include an "infrastructure exploration" [25] in which students plan and execute a local journey informed by readings from Langdon Winner, Rayvon Fouché, Simone Browne, and others, then present their observations to their classmates in ways that facilitate further discussion. For the capstone project in Race & Technology, students may choose to propose a redesign of either a specific technology or a STEM curriculum, drawing on the course readings and discussions. The readings lists for both classes are included as Appendices A and B.

The Gender & STEM course was developed and taught by Mary Armstrong, a scholar of literature and gender studies whose research has included several NSF ADVANCE grants focused on supporting diverse women STEM faculty through institutional transformation; the Race & Technology course was developed and taught by Jenn Stroud Rossmann, a mechanical engineering professor who served as founding co-director of Lafayette College's Center for Inclusive STEM Education, and who developed the cross-listed course in consultation with the chair of Lafayette's AFS program. Our strong commitment to understanding and transforming the culture of STEM informs our development and teaching of these courses.

Methods

The driving research questions for this work are: (1) what knowledge and attitudes do engineering students take forward from STEM-themed courses in gender studies and ethnic studies; (2) how do these courses influence students' engineering identity; and (3) is engineering students' critical consciousness developed by these courses?

We have used mixed methods to explore these questions. In both classes, we administered pre- and post-class surveys to students; in this study, we focus on the survey responses of STEM majors in four offerings of these courses, an *N* of 31. We administered pre- and post-class surveys for two offerings of Race & Technology and one offering of Gender & STEM, as well as a pre-class survey for the spring 2024 offering of Gender & STEM. Although our surveys do not request ethno-racial or gender information, data from our Office of Institutional Research indicate that STEM majors in AFS were 42% white and 42% male, and those in WGS 66% white and 12% male. For comparison, we administered the same pre-class survey to junior mechanical engineering majors (A *N* of 60, 85% white and 87% male).

The survey instruments included: questions previously validated as measurements of STEM identity development [26], including asking students to identify both the strengths they brought to the class as well as challenges they anticipated; and the single-item assessment proposed and evaluated by McDonald et al [22], shown in Figure 1. Surveys before and after the classes asked participants to select the degree of overlap between the circles that best represented their own identity, and to explain the indicated degree of overlap.

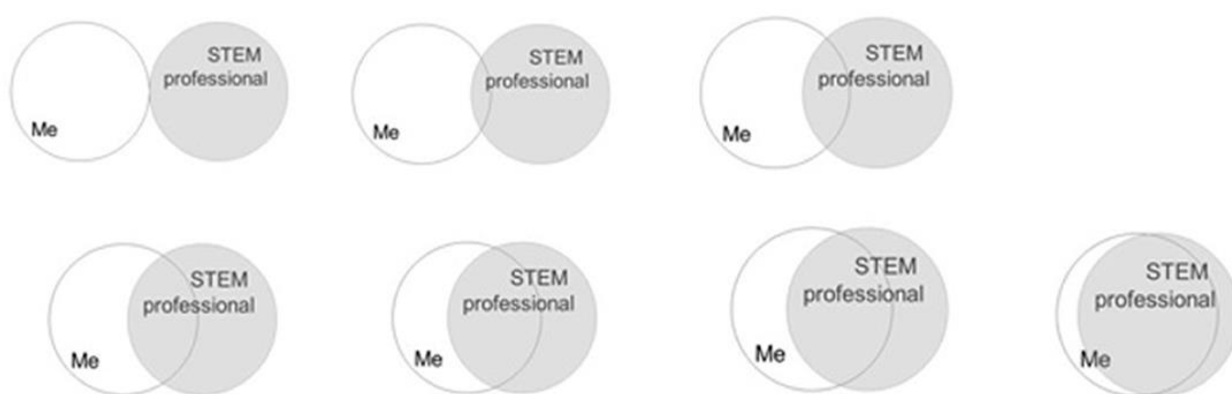

Figure 1. "Single item measure" of STEM identity, from McDonald et al [18]. In the current study, survey respondents and focus group participants were asked to select the image that best represented their own identity, and to discuss whether this representation had shifted over time.

While these surveys gave us information immediately preceding and following the courses, to deepen our understanding of the longer term influences, we also facilitated focus group discussions with female STEM majors who had completed the WGS course at least a year earlier. These discussions were recorded and transcribed by a third-party service. Our study was reviewed and exempted by our institution's IRB, and both surveys and the focus group were preceded by students' providing their informed consent.

The short-answer responses and focus group transcripts were coded for themes [27]. Our survey coding process was inductive and iterative, allowing themes to emerge. Focus group participant responses were coded according to their alignment with themes observed in prior survey data. Participant responses in the focus group discussions were triangulated with these survey responses.

Results and Discussion

On the pre-class survey, two questions probed students' self-assessment of their strengths and anticipated challenges in these classes; these questions drew on the research of Singer [26] on measurement of STEM identity.

Some themes emerged from these pre-class responses among engineering students in Race & Technology, who commonly identified their strengths as analytical thinking and time management, but who anticipated challenges in "navigating discussions around sensitive topics" and "understanding complex interdisciplinary concepts." Students linked their own identities to these challenges: "white privilege" was cited by multiple students, and one student of color observed, "It is a challenge to sit in a class talking about race as an underrepresented person. There are days I will have to take time to process more than speak."

In the pre-class surveys for Gender & STEM, engineering students cited being open-minded and hard-working as strengths. They similarly expressed anxiety about being confronted with difficult topics: "I think it will be a challenge to see other viewpoints when looking into gender and STEM" and "I think I may have some biases about gender representation in STEM that may be difficult to overcome." Prior to taking Gender & STEM, an engineering student anticipated the challenge of "Pushing myself to think more deeply about the influence I have on many others in my field of study," a response that appeared to anticipate the critical reflection to come, and even the potential for this student to take critical action by being more intentional about the "influence" they have.

On both the pre- and post-class surveys, two questions asked how students felt the course content of either Gender & STEM or Race & Technology would relate to their major curricula and to their professional practice. One student's pre-class comment anticipated that their WGS experience would lead to reflective action: "I think this course can help me gain skills to tackle [discriminatory] experiences and use my voice to make my field more inclusive." The post-course responses from STEM students were coded for themes [27]; results are summarized in Table 1.

Table 1. Emergent themes and representative student comments in post-course surveys

Theme	**Representative comments**
Awareness of Social Construction of STEM	• "I think of **why things were made the way they are** and how certain people are favored over others when creating different systems." (WGS) • "This class has revealed to me that technology is not value-neutral. It has revealed the biases embedded in many technologies which I was unaware of." (AFS) • I learned: "race itself is a technology that constructs other technologies. I also learned a great deal about the history and politics behind artifacts and the not-so-obvious connections between racism and tech design." (AFS)
Awareness of Inequity or Bias in STEM	• "[What I learned in] this course will help me think about engineering from a more people-centered approach, and remind me to consider how important it is to be inclusive and equitable within STEM." (AFS) • "I think of why things were made the way they are and **how certain people are favored over others when creating different systems**." (WGS) • "This class has made me more aware of the many different ways technology affects society (and vice versa) and I will keep that in mind when pursuing my career in engineering so I am less likely to produce work that harms people inadvertently." (AFS) • I expect that I will experience discrimination and other such behaviors once I enter the professional world due to my identities. (WGS)
Perseverance and Optimism	• "I have gained so much power in my ability to acknowledge the limits of objectivity." (WGS) • "[This class] has given me the language and framework to recognize things that I see happening within [the College's] STEM community, and how to combat stereotype threats. The class has inspired me to also be aware of the impact of "objectivity" in STEM and made me want to be more critical of the things that I'm taught in my major." (WGS)

Advocacy and Action	● "knowing the history and gendered framework of STEM has given me language to call out the more subtle and nuanced ways that discrimination shows itself in the department." (WGS) ● "This knowledge [will be] essential for designing equitable and inclusive technological solutions" (AFS) ● "it will help me create designs that are for everyone." (AFS) ● "It has taught me what to look for in the world both in and out of technology and how I can use what I learn to make impactful change. It has also shown me principles to keep in mind when thinking about design." (AFS)

The first two themes, Awareness of the Social Construction of STEM and Awareness of Inequity in STEM, resonate strongly with the "critical reflection" about and "problematizing" of the culture of STEM/engineering associated with developing critical consciousness, while the third and fourth themes, Perseverance & Optimism and Advocacy & Action, correspond to the bias toward action required by critical consciousness. Students frequently used words like "will" and "can," indicating a proactive mindset. Their stated plans to "call out…discrimination," and "address [inequity]" demonstrate their intention to act on their new knowledge and reflect a shift from being an entrant into STEM cultures to being a change-maker of STEM cultures.

Students were also asked to consider the graphical tool developed and validated by McDonald et al [22] (Figure 1). After completing the Race & Technology class, engineering students reported feeling more like STEM professionals (the degree of overlap they identified either increased slightly or stayed the same), explaining the ways that the knowledge gained in the course made them feel more confident in their own engineering identity, ascribing value to their increased understanding of the interactions of "technology and society," and "recognizing my own merit" as a woman of color whose experience was "previously colored by racism and imposter syndrome."

After completing the Gender & STEM class, engineering students reported a similar sense of empowerment due to their learnings, as well as agency to act within the culture of STEM. One student's comment, "I will be a professional person in STEM quite soon," underscores a forward-looking perspective, emphasizing a commitment to and confidence in achieving professional status in the STEM field. Learning about structural inequalities within STEM and debunking stereotypes has boosted confidence in belonging in the field. We observe students' recognition that the term "STEM professional" had previously seemed exclusionary, but students have found frameworks to challenge such notions and feel better equipped to navigate STEM spaces.

Figure 2 illustrates engineering students' response to the graphical measure of STEM identity. If the graphical measure options are assigned numerical values from 1 (least overlap) to 7 (most overlap), the average overlap increases from 4.2 to 5.3 for STEM students in WGS, and from 4.6 to 5.6 for engineering students in AFS. (As a comparison, engineering students entering a junior-level mechanical engineering course were asked to respond to the graphical measure, and the average overlap was 4.9; this is measurably higher than the pre-class overlap reported by students in AFS and WGS.)

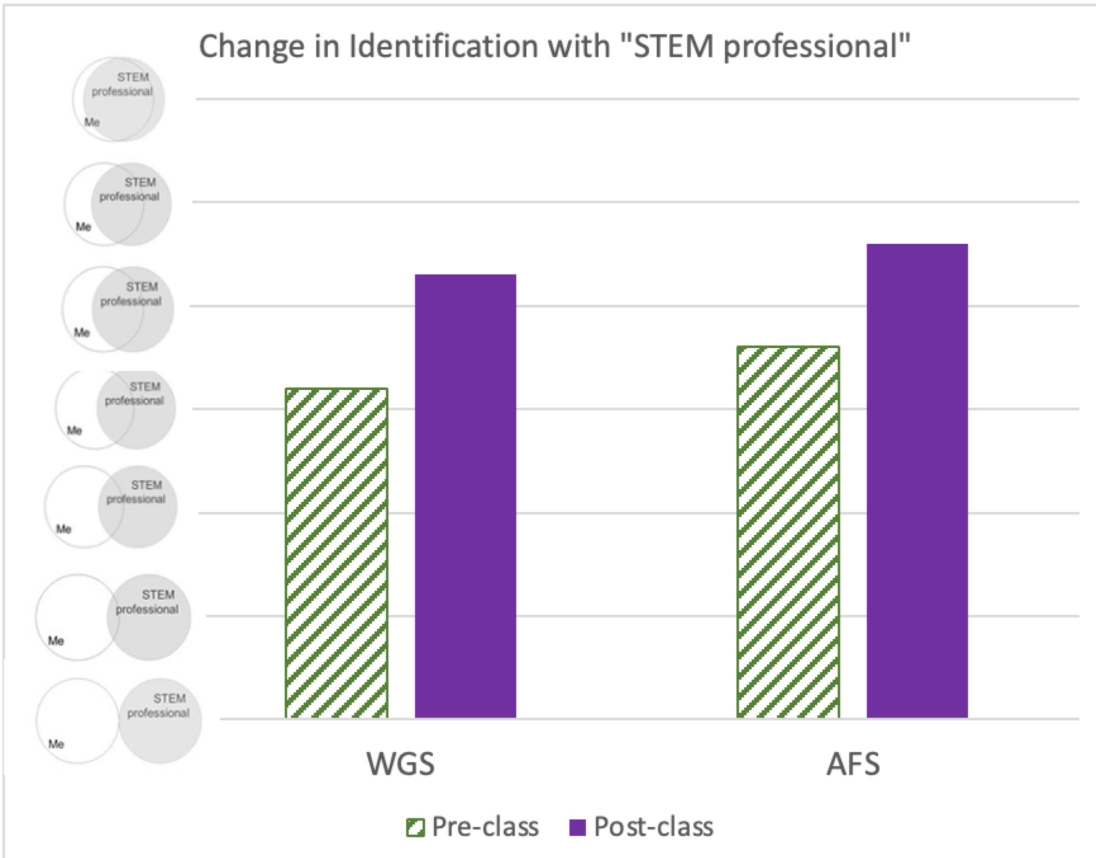

Figure 2. Average degree of overlap between personal and "STEM professional" identities indicated by survey respondents before (green dashed) and after (solid purple) classes in gender studies (WGS) and ethnic studies (AFS), and before and after a junior-level mechanical engineering (ME) class.

While these responses indicate an increase in self-assessed "fit" with STEM identity, the comments in Table 2 add texture and context. Table 2 shows the themes of the comments students in both courses made about the degree of overlap they felt before and after these courses.

Table 2. Themes and representative comments about the degree of overlap reported in Figure 2.

Theme	Representative Comments
Awareness of Systemic Inequity in STEM	• "I was pretty confident in my abilities to be a STEM professional before this class, but after learning about the structural inequalities that women face to enter the field and the false narrative that 'men are more suited for STEM', I now have full confidence that I belong in this area." (WGS) • "[this class helped me] achieve a better understanding of systemic factors that contribute to my experiences in my STEM field. This framework is helpful and more empowering for me." (WGS) • "i think this class has shown me how i can be a stem professional by increasing my knowledge of technology and its relations to society." (AFS)
Personally confronting stereotypes	• "[I do not fit the] traditional model of what a STEM professional is. That said, I will be a professional person in STEM quite soon, so I do sort of see myself occupying that space." (WGS) • "I think my perception of a STEM professional was previously colored by racism and impostor syndrome, but the knowledge gained in this course has empowered me to recognize my own knowledge/merit as being on par with other STEM pre-professionals" (AFS) • "A lot of my discomfort around identifying as a STEM professional came from my position as neither white, nor male, nor heterosexual. It didn't feel like a term that was made to include me, rather to separate me from 'true' STEM people. I've come to recognize [that] while that is very much the case, I have frameworks with which to challenge these notions, and I feel better equipped to be in STEM spaces and be a STEM professional." (WGS)
Resilience (Perseverance and Optimism)	• "I don't think I am a professional yet but I believe I can get there" (WGS)

In students' comments about the degree of overlap they indicated, we observe that the courses appear to have enhanced their critical consciousness about STEM culture: students evince a "problematized" understanding of STEM disciplines as containing "structural inequities," "systemic factors contributing to my experiences," and stereotypes about who is considered a "STEM professional." They appreciate the new language ("imposter syndrome," "bias"), "knowledge," and "frameworks" the courses have provided, and feel "empowered" and "confident," more able to persevere and to feel agency, as a result. While these individual metrics are positive outcomes of critical reflection, they do not on their own predict intervention and transformative critical action. Themes of resilience and perseverance are highly individualized and not necessarily correlated with liberatory action—they could even reflect student acceptance of and assimilation into the status quo.

A stronger reflection of critical consciousness may be the way students describe the professional work they will do as being focused on making "impactful change," "designing for everyone" (noting that this is distinct from historical practice), and increasing the inclusivity and accessibility of engineering processes and products. These comments indicate that students feel inclined toward *action* as a result of the problematizing, reflective of an increased development of critical consciousness.

Some students' response to this identity measure was affected by intersectionality. One student added context to the relatively low degree of overlap they reported: "I believe besides being a STEM major, I also carry many other identities with me as a person, although the majority of the work I do goes into my major."

These students' comments suggest that their reported "increased overlap" of identities may follow from an enlarged, "problematized" sense of STEM identity itself.

Reframing "STEM Identity"

A semester or more after completing the Gender and STEM course, students participated in a focus group facilitated by the first author [2,23]; during the interviews, these students were asked to respond to the graphical tool to measure STEM Identity Formation [22]. We illustrate the results in Figure 3 with a purple rectangle indicating the average overlap indicated by focus group participants. (The blue and red rectangles show the least and most overlap selected.) Our hypothesis that students' sense of belonging in STEM would increase because of exposure to WGS content led to an expectation of a high degree of overlap. However, when asked to select the (visual) degree to which their own identity overlapped with that of a "STEM professional," respondents tended to choose moderate degrees of overlap, with an average numerical value of 4.0.

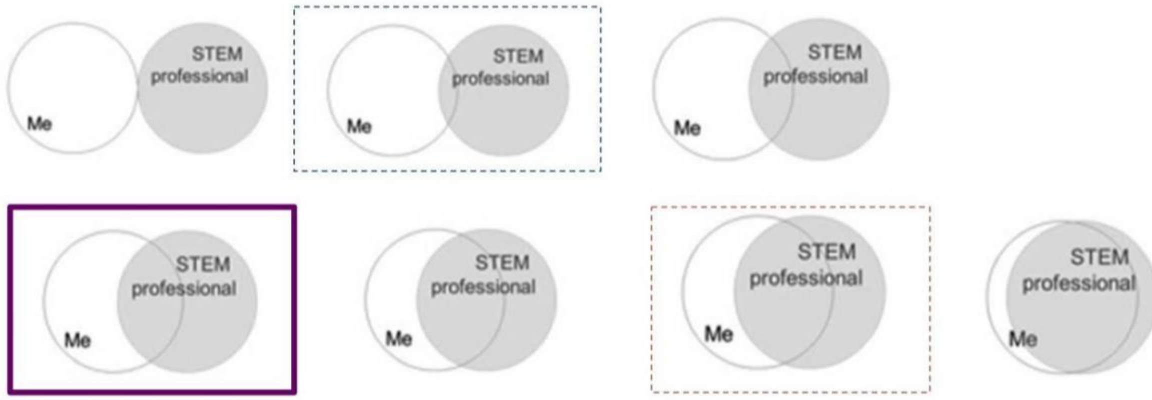

Figure 3. Average degree of overlap between personal and "STEM professional" identities indicated by focus group participants, shown with purple rectangle. Blue and red dashed rectangles show least and most overlap indicated by participants.

As they considered the graphic, participants verbalized their reasoning about becoming newly appreciative of the potential breadth and flexibility of both these circles, more critical of conventional STEM professional identity, more aware of the socially constructed nature of that identity, and more comfortable with a less-than-complete overlapping. Discussion of this graphical metric suggested that participants' WGS coursework had countered the prior expectation that they needed to mold themselves into a conventional "STEM professional identity" and hence the coursework had to some degree undercut the presumed neutrality of even the identity itself. This discussion was consistent with the notion that WGS instruction had been in some way liberatory.

> Participant A: before I definitely had a more narrow view of what a STEM professional looked like. Even just in thinking about the biases like, oh, some people think this; therefore, I might not be seen as this. And so [WGS has helped me] chang[e] my identity from what other people think of me to what I think of me and how broad a definition of a STEM professional can be [has changed both circles over time].

> Participant B: I don't know how to get my circles [more] overlapping [but] it's actually not my problem. I think that's what I've gained … is to know that it's not my fault.

Our study also points to potentially important findings regarding the effect of WGS coursework on STEM identity stereotypes. The graphical metric of STEM identity [22] revealed that in addition to providing affirmation and empowerment, WGS coursework had also been liberatory, freeing students from the normative (abled white male) default understanding of who does STEM. Rather than feeling compelled to contort themselves into a narrow definition of "STEM Identity," students from WGS 250 questioned the value of a socially constructed identity they now had the ability to critique. Focus group participants were comfortable with a less-than-complete overlapping of their own identity with the conventional idea of a "STEM professional." While McDonald et al [22] describe their tool as measuring "typicality," students exposed to

WGS frameworks felt confident about their atypicality and liberated to "break the mold." Our study participants explained that their work in WGS had helped them understand that a partial overlap was neither their "fault" nor a problem in need of correction.

Students report that these critical lenses on engineering are vision-clarifying and -broadening, and motivate them to persist in and transform the culture of engineering: in other words, students develop a critical consciousness relative to engineering culture supported by this coursework. As another focus group participant mentioned, "after several semesters of seeing many women and people of color drop the major while my internships were in heavily white/male environments and the curriculum focusing on white/male accomplishments I began to seriously question my place. After taking WGS 250, it's easier to do something about it and like possibly change your surroundings or talk to someone about it."

Confronting stereotypes, "breaking the mold," and recognition of one's own merit were powerful themes in student responses to the STEM identity measure. We note how many of the students report their own identities' incongruence with a stereotypical STEM professional – and their sense, after this coursework, that this very incongruence is a strength.

Implications

This type of coursework may disrupt or "break the test" of STEM identity by expanding students' idea of their own identity as well as leading them to question the rigid preconception of "STEM professional" identity itself, which through this coursework is increasingly understood ("problematized") to be socially constructed and exclusionary. Such disruption may be particularly valuable to students minoritized in STEM. Cech et al. [28] demonstrated that the construction of a professional engineering identity is gendered, in ways that "may leave women in engineering with less career-fit confidence than men," undermining women's engineering identity formation.

Furthermore, through developing critical consciousness, a student may increasingly develop an identity as an active and engaged citizen, "someone who has a sense of civic duty, feeling of social connection to their community, confidence in their abilities to effect change, as well as someone who engages in civic behavior" [29] Such an identity, while congruent with the ideal of an engineer working for the public good, can be at odds with the model of a professional engineer beholden to address the problems posed by clients, managers, and funding agencies. The pernicious myth of objectivity can make engineering knowledge feel soulless, divorced from social issues, and context-free such as to disempower and alienate students [30]. Angela Bielefeldt's work suggests that this drives away students inclined to pursue engineering in order to do social good [31].

Critical consciousness, as exemplified by the pedagogies of gender and ethnic studies, may well (re-)engage those students, as it demonstrates that engineering identity can be reconciled with that of "problem-poser," "community servant," and "actor." The value of developing such critical consciousness within and about the culture of engineering itself goes beyond mere retention or even "sense of belonging" – it thus contributes to these students' capabilities as engineers and practitioners. STEM students with critical consciousness may be more likely to develop scientific knowledge that matters, and engineering that is humane.

Castaneda and Meija [3] proposed that Accreditation Board for Engineering (ABET) standards might facilitate [civil] engineering educators focusing on critical consciousness, noting the overlap between ABET student learning outcomes and the traits of heightened CC. They felt the project-based work in civil engineering curricula positioned students to apply their technical knowledge to highlight the social, political, and economic impact of engineering solutions, and especially to gain new perspectives from community stakeholders and professional engineers. Holly [10] hopes such engagement with stakeholders "may help [students] notice their own prejudices" and that "faculty could assist with challenging these conceptions while developing new knowledge, skills, and language." In the current study, some student comments made following the Race & Technology class highlight a desire to use the course knowledge to serve "stakeholders," "to design technology for all," and seem to support this reasoning. As one student put it, "When I work with clients or create products, I will be more focused on hearing their stories and doing what's best for them and not just for the utility of the project."

One student anticipated the impact that their coursework might have "if I go into tech…knowing about the powers of authority and who has the power and what needs to change and [having] a bigger heart and understanding of what goes on in people's lives." This outcome is important for both minoritized and relatively privileged students; as Kokka [8] notes: "social justice work calls on the participation of the privileged and the oppressed." The myth of STEM neutrality harms and constrains all participants in the culture of STEM, and privileged students must collaborate in solidarity with others to transform this culture. This is in agreement with the work of Diemer et al [15], who observed that in addition to its power for those experiencing oppression and marginalization, critical consciousness also has value for those who experience relative privilege, who may also reflect critically about inequity, "develop the agency to produce change, and participate in critical action to create a more just world based on some aspect of their identity that is marginalized (e.g., gender), or their alignment as an ally."

Still, we hold space for the fact that, as articulated by the student observing the "challenge" of "a class talking about race as an underrepresented person," different students experience the revelations and transformations of critical consciousness differently. Riley and Clarins [13] previously observed a resistance to liberative pedagogy. In continuing work, we will explore these differences further. A longer range study investigating whether and in what ways the "transformative potential" of critical consciousness is converted to action may offer an opportunity to gather data outside specific course contexts as well as to surface lasting impacts.

We note that students responded to the McDonald graphical measure differently in different data-collection contexts. There is, therefore, some tension between the two sets of results: in-class quantitative surveys for both WGSS and AFS classes show an average movement towards "STEM Professional" identity, while later qualitative data from the focus group suggest a deeper sense of flexibility and an elevated critical perspective on the nature of STEM professional identity itself. This suggests that in course-specific surveys, students appear to be using the graphical measurement tool to communicate their ability to persist and survive in STEM, while in the more reflective focus group context, students more strongly express the ability to thrive in STEM as they are, and less of a need to conform. The later data set, from focus group discussions, especially represents “critical consciousness” because it indicates viewing normative STEM culture as something in which one can be present without conforming to another identity.

A potential limitation of the current study is the self-selection of students choosing to enroll in these classes. We note that their demographic makeup, and their initial thoughts about “fit” and STEM identity, are measurably distinct from those of the student body in STEM at our institution (for example, in the mechanical engineering class surveyed).

In a utilitarian sense, these student responses reflect a potential improvement in their skills as engineers who must meet individual and social needs. Many frameworks for engineering design processes use “empathy” to describe developing understanding in order to identify and meet these needs; the importance of appreciating social context and systemic perspectives has been noted, particularly in the context of “service”-coded projects like the Grand Challenges [32]. Kokka [8] proposes the development of “critical civic empathy” as a component of critical consciousness; this “is about imaginatively embodying the lives of fellow citizens while keeping in mind the social forces that differentiate our experiences as we make decisions about our shared public future” [33].

Our investigations of these courses, like Riley’s critiques, “point to the value of a liberal arts education—one that at its core promotes critical thinking, not merely knowledge or awareness of social issues but the ability to think originally and act in response.” [11] Liberal education itself—and particularly curricula in “identity studies” fields— may be resonant with these aspects of critical consciousness. The two courses examined in this study focus both the reflection and the inclination toward action on STEM itself. They present not general education checklists for “rounding out” engineers across campus but integrated, interdisciplinary opportunities for students to reflect on and take action within and upon engineering culture.

The relationship between this interdisciplinary coursework and students’ critical consciousness may play a role in shaping students’ sense of the political conditions of education power and practice, leading to larger-scale “transformative potential.” Students’ engagement in and motivation to contribute to social justice and socially relevant engineering work resonates with both Friere and ABET. Particularly at a moment when such coursework and critical theorizing is under public, institutional, and legislative attack, the positive outcomes for both students and the culture of STEM are worth defending.

Conclusions

Investigating the influences of STEM-themed coursework in gender studies (“Gender and STEM”) and ethnic studies (“Race and Technology”) for engineering students suggests that such coursework develops students’ critical consciousness within and about the culture of engineering. Survey responses and focus group interviews demonstrate that students in these courses “problematize” STEM by reflecting critically on its social construction and inequities, and feel empowered to take “critical action” within the STEM curriculum (“calling out” discriminatory practices, for example) and as professional engineers who practice different, more inclusive and just values than the historical norm. These students express confidence and optimism about persisting within and transforming the culture of engineering. Developing such critical consciousness thus goes beyond improving retention or even "sense of belonging" – it contributes to these students' capabilities as engineers and practitioners. Student responses to instruments measuring "engineering identity" highlight and reveal the ways in which this critical consciousness has developed, expanding their conception of both stereotypical archetypes and of their own capacities. By problematizing the use of instruments to measure "fit" and "engineering identity," our findings strengthen the argument for the value of these kinds of "STEM Studies" courses in gender and ethnic studies, and accompanying interventions in the engineering curriculum.

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APPENDIX A

WGS 250: Gender & STEM Reading List

Objectivity and Feminist Science Studies: Gender and Race

Simone de Beauvoir, Excerpts from *The Second Sex*

Evelyn Fox Keller, "Gender and Science"

Sandra Harding, "Thinking about Race and Science" and "With Both Eyes Open" (from *Science and Social Inequality: Feminism and Postcolonial Issues*)

Life Sciences: Nature, Nurture, No Thanks?

Londa Schiebinger "Biology"

Emily Martin "The Egg and the Sperm"

Upchurch and Fojtova "Women in the Brain: A History of Glial Cell Metaphors"

Anne Fausto-Sterling "The Bare Bones of Sex, Part I: Sex and Gender"

Cordelia Fine**,** *Delusions of Gender: How our Minds, Society and Neurosexism Create Difference* (pp xv-117)

Cordelia Fine, *Delusions of Gender* (pp 118-239)

Human Genome Project

Barbara Katz Rothman, "For Whom the Bell Curves, "Rates and Races," "The Human Genome Diversity Project"

The "Science" of Homosexuality

Jennifer Terry, "Anxious Slippages Between 'Us' and 'Them:' A Brief History of the Scientific Search for Homosexual Bodies"

Roger Lancaster, "Familiar Patterns, Dangerous Liaisons"

FILM: *Changing Our Minds: The Story of Dr. Evelyn Hooker*, dir. Richard Schmiechen

Sexual Selection

Sarah Hrdy, "Empathy, Polyandry and the Myth of the Coy Female"

Joan Roughgarden, "The Theory of Evolution"

Physics and Math

Londa Schiebinger "Physics and Math"

Barbara Whitten, "(Baby) Steps Towards Feminist Physics"

Tech/Computer Science

Judy Wajcman, "Feminist Theories of Technology"

Bardzell, "Feminist Human Computer Interaction (HCI)"

Elizabeth Churchill "Gender and Design"

Jane Margolis "Normalizing the Racial Divide" and "Claimed Spaces"

Carol Cain Miller "When Algorithms Discriminate"

T.L. Taylor, "Becoming a Player: Networks, Structures and Imagined Futures"

Nick Yee, "Maps of Digital Desires: Exploring the Topography of Gender and Play in Online Games"

Engineering and Design

Judy Wajcman, "The Built Environment: Women's Place, Gendered Space"

Patricia Hill Collins, "Toward a New Vision: Gender, Race and Class"

Koskela and Pain, "Revisiting Fear and Place: Women's fear of attack and the built environment"

Foor and Walden, "'Imaginary Engineering' or 'Re-Imagined Engineering': Negotiating Gendered Identities in the Borderlands of a College of Engineering"

Gender and "Doing STEM"

Virginia Valian "Gender Schemas at Work" and "Effects on the Self"

Margolis et al "Geek Mythology" and "Living among the Programming Gods"

Moss-Racusin et al, "Science faculty's subtle gender biases favor male students"

Molly Dingle, "Gendered Experiences in the Science Classroom"

Melanie Tannenbaum, "The Problem when Sexism Just Sounds so Friendly"

Rebecca Solnit, "Men Explain Things to Me"

Gendered Innovations (Londa Schiebinger, Stanford University)

APPENDIX B

AFS/EGRS 220: Race & Technology Reading List

Constructing Race

Audrey Smedley & Brian Smedley, "Race as Biology Is Fiction, Racism as a Social Problem Is Real: Anthropological and Historical Perspectives on the Social Construction of Race," Am Psychologist, 2005

Michael Omi and Howard Winant, eds., Racial Formation in the United States, Second Edition, pp. 3-13.

bell hooks, "Postmodern Blackness," 1990

Constructing Technology

Langdon Winner, "Do Artifacts Have Politics," *Daedalus*, 1980

Trevor J. Pinch and Wiebe E. Bijker, "The Social Construction of Facts and Artefacts: or How the Sociology of Science and the Sociology of Technology might benefit each other," 1984

Race and/as Technology

Bruce Sinclair, "Integrating the Histories of Race and Technology," from *Technology and the African-American Experience Needs and Opportunities,* 2004

Ruha Benjamin, Introduction to *Race After Technology,* 2019

Alondra Nelson, Introduction to *Future Texts,* 2002

Wendy Chun, Race and/as Technology; or, How to Do Things to Race, *Camera Obscura,* 2009

Surveillance and Colonialism

Frantz Fanon, "Algeria Unveiled" and "This is the Voice of Algeria," from *A Dying Colonialism,* 1965

Simone Browne, On the Surveillance of Blackness, 2015

Owen Dwyer & John Paul Jones III, "White Socio-spatial Epistemology," 2000

Ainissa Ramirez, "Capture," from *the Alchemy of Us,* 2020

Infrastructure

Rayvon Fouché, "The Wretched of the Gulf: Racism, Technological Dramas, and Black Politics of Technology," 2015

Shannon Mattern, “Infrastructural Tourism,” 2013

Ben Cohen and Jenn Stroud Rossmann, “The Internet is Railroads,” 2021

Biomedicine

Alondra Nelson, “Pursuit of African Ancestry,” from *The Social Life of DNA,* 2016

Jenny Reardon and Kim TallBear, “Your DNA Is Our History: Genomics, Anthropology, and the Construction of Whiteness as Property,” 2012

Aaron Panofsky and Joan Donovan, “Genetic ancestry testing among white nationalists: From identity repair to citizen science,” 2019

Patricia Hill Collins, “It’s all in the Family: Intersections of Gender, Race, & Nation,” 1998

Cyberculture

Lisa Nakamura, “Where do you want to go today,” 2002

Andre Brock, “Black Purposes of Space Travel,” 2020

Joy Buolamwini et al., *Coded Bias*

Yarimar Bonilla and Jonathan Rosa, “#Ferguson: Digital protest, hashtag ethnography, and the racial politics of social media in the United States,” 2015

Héctor Beltrán, “Code Work: Thinking with the System in Mexico,” 2020

Alternative Futures

Lisa Poggiali, “Digital futures and analogue pasts?: Citizenship and ethnicity in techno-utopian Kenya,” 2017

Rayvon Fouché, “Say It Loud, I'm Black and I'm Proud: African Americans, American Artifactual Culture, and Black Vernacular Technological Creativity,” 2006

Boots Riley, *Sorry to Bother You*

Katherine McKittrick, from *Dear Science,* 2021

Sasha Costanza-Chock, from *Design Justice,* 2020