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Principles of Equity-Centered Engineering Education: An Element of a Curricular and Instructional Change Framework

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Principles of Equity-Centered Engineering Curriculum and Instruction: An Element of a Developing Framework

Introduction

In this paper, we describe six principles for equity-centered engineering education that we are developing as part of a larger effort to provide professional development for engineering instructors who wish to incorporate equity content into their courses. Incorporating content related to equity in engineering has been shown to support broadening participation, since minoritized students often pursue STEM degrees due to an interest in learning how to leverage their degree for positive social impact (e.g., [1] - [5]). A broadened view of what counts as engineering content is aligned with a sociotechnical view of engineering and educational efforts to authentically prepare students to address real-world engineering challenges (e.g., [1], [6] - [8]). While a sociotechnical view of engineering does not necessarily center equity, curricular and instructional efforts to integrate the social and technical dimensions of engineering afford opportunities to engage issues of equity as instructors seek to develop students' understandings of the social context and impacts of engineering work. Conversely, engineering courses and activities focused on equity or justice can support students' development of sociotechnical thinking [9]. Three of the principles we describe in this paper focus on the need for curricular attention to sociotechnical integration and the promotion of an equity lens in engineering education.

The teaching of equity content must be done in the context of an equitable learning environment in which instructors model equity-mindedness in course design before asking students to engage in their own considerations of equity (e.g., [10] - [14]). An equitable learning environment also supports retention of minoritized student populations (e.g. [15], [16]) and goes hand-in-hand with equity-centered curricula in comprehensive efforts to broaden participation in engineering. Additionally, courses that embed sociotechnical and equity-centered views of engineering and that ask students to engage in reflection and discussion must be organized to scaffold such activities. Equitable learning environments promote the sharing of diverse perspectives and mitigate harm to students' identities and sense of belonging. Equitable classrooms also require equitable assessment practices, and, when teaching equity-centered content, that content must be assessed. Including equity-centered content in assessment sends a clear message to students about the value and role of equity considerations in engineering work. Three of our principles for equity-centered engineering education are therefore instructional in focus and address the development of equitable classroom environments, including equitable assessment strategies, and the need for assessment of equity content.

To date, most publications on equity-centered engineering course implementations describe efforts in engineering design or ethics courses and modules. This may suggest that an equity lens is only or most relevant in those courses; however, if the goal is to promote students' capacity for equity-minded engineering practice, educators must center equity in a variety of impactful courses across students' academic paths [17]. Indeed, Leydens and Lucena [18] argue that engineering science courses are perhaps the most influential courses in developing students' definitions and conceptions of engineering, making these courses an important context in which to integrate equity. The principles we describe in this paper are part of our efforts to advance the goals of integrating sociotechnical and equity-centered content across a range of engineering courses and ensuring equitable instructional approaches and learning environments. Our principles are intended to work together and are numbered for ease of use, but we do not claim that any principle is more or less important than another. They work together and should be considered together, but could be implemented in steps and different orders, depending on instructors' needs and contexts. In describing each principle, we cite supporting literature and findings from our interviews with equity-oriented engineering instructors, and we provide illustrative examples of implementation in a variety of course contexts. We also highlight the interactions of curriculum and instruction across principles.

Before describing our principles of equity-centered engineering curriculum and instruction, we provide a project overview and description of our development process. Describing our development process involves information on how we identified relevant supporting literature for the principles and gathered examples of how to enact the principles from engineering instructors. Following that overview, we present the six principles, including the supporting literature and evidence for each, and examples of actionable implementations from our interviews. We close with a brief discussion of our future framework development work.

Project overview

The six principles presented in this paper constitute a key component of a framework we are developing to support engineering instructors to integrate equity issues that arise in engineering work into course content and instruction. We provided an overview of this effort in our previous work-in-progress paper [19]. Another major component of our framework is what we have called foundational concepts, or the underlying habits of mind that support implementation of the principles presented in this paper. We are working towards sharing those foundational concepts, as well as developing the professional training infrastructures to support instructors in building those habits of mind. In this paper, we present the six principles–one of the main pieces of the framework–in the interest of obtaining feedback at this stage in the development process. The paper is thus conceptual in nature, integrating evidence from our explorations of the literature and interviews with engineering faculty to explain the rationale of each of the principles.

The framework development is part of an NSF Broadening Participation in Engineering (BPE) grant to create the Teaching Engineering Equity (TEE) Center. The TEE Center supports existing and new work aligned with the College of Engineering's Diversity, Equity, and Inclusion (DEI) strategic mission. The TEE Center consists of three foci, which have over time become more holistically connected and mutually supportive: (1) designing a framework for equity-centered engineering education, (2) creating a collection of equity-oriented learning activities within specific engineering courses and disciplinary contexts, and (3) developing an infrastructure to train instructors in equity-focused teaching. This paper focuses on specific elements of the framework being developed as part of Focus 1.

For our purposes, equity-centered engineering education is grounded in an understanding of the impact of engineering on societal (in)equities. Our framework is intended to support engineering instructors in promoting the development of students' equity orientations through course experiences that affirm learners' identities and lived experiences; center the sociotechnical nature of engineering; and prioritize equitable teaching and assessment practices. Our ultimate goal is for students to develop engineering equity-mindedness, involving the following learning objectives:

(a) Obj. 1: awareness and recognition of engineering as a sociotechnical field and occupation that requires understanding of micro-, meso-, and macro-level social contexts;
(b) Obj. 2: capacity to identify and reflect on one's positionality and the ways one's engineering practice can affect societal (in)equity;
(c) Obj. 3: capacity to consider, individually and with others, how societal (in)equity is or can be shaped by current and future engineering work;
(d) Obj. 4: willingness to engage others (e.g., current peers, collaborators, future work colleagues) in discussions of equity in engineering.

To teach courses that meet those aims, engineering instructors also need to work toward those same learning objectives in their own understanding, as well as learn to implement our framework in their courses. In other words, faculty must work on the same understanding of equity-centered engineering as students, if they are to cover such ideas in courses, and they must also develop equity-mindedness toward the classroom context, given their role as instructors. Ultimately, equity-centered engineering education requires a tandem strategy of integrating equity in both instructional approaches and in course content.

Overview of the framework development process

The framework development process has been a team effort; the team of authors on this paper, working on Focus 1 of the Center, includes members of a research team consisting of a faculty member, a postdoctoral researcher, and graduate students, as well as an advisory group of "TEE Scholars", consisting of faculty from the fields of engineering, higher education, and sociology, and professional staff from the Center for Research on Learning and Teaching in Engineering and from the Center for Socially Engaged Engineering and Design.

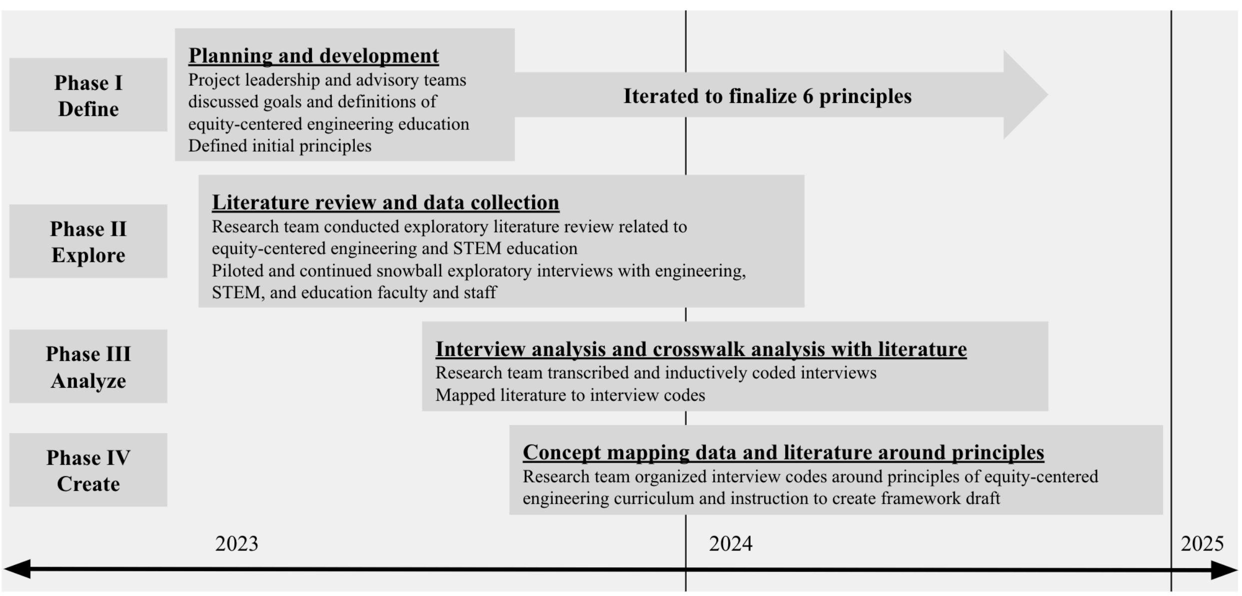

Fig. 1. Timeline of project phases

Phase I: Planning and development

In the first phase of our work (see Fig. 1), the research team and the Scholars engaged in iterative discussions to clarify our goals and definitions of equity-centered engineering education. Through these conversations, we generated six principles that we view as necessary elements of equity-centered engineering curricula and teaching. The principles initially functioned as guiding orientations, but we increasingly found them useful for organizing other emerging framework elements, as will be discussed in the following sections.

Phase II: Literature review and data collection

In addition to conversations about how to define equity-centered engineering education, the research team engaged in two main activities supporting the development of the framework (Phase 2; see Fig. 1): literature reviews and interviews with engineering, STEM, and education faculty and staff. The research team conducted reviews of literature in engineering, STEM, and education – to identify efforts to center equity in STEM curricula and instruction – and equity-oriented theories.

At the same time, we conducted 30 exploratory, semi-structured interviews with equity-oriented faculty and staff in engineering and STEM education, which includes seven pilot interviews also used to refine the interview guide. Our sample consisted of three teaching and learning center staff members as well as tenure and non-tenure faculty of all ranks from across the country, and from a variety of engineering disciplines. The interview guide asked participants to identify what they considered essential for equity-centered engineering education. Instructors were encouraged to discuss their experiences with integrating equity into their courses, focusing on teaching methods and course content.

Phase III: Interview analysis and crosswalk analysis with literature

In Phase 3 (see Fig. 1), to analyze the interviews, we qualitatively coded the transcripts and built a codebook from an initial set of codes aligned with our interview topics (e.g., motivation, learning objectives, etc.), inductively adding and developing codes. Each transcript was coded by at least two researchers, and the team discussed to resolve discrepancies and iterate on the codebook.

Unsurprisingly, given the prevalence of certain ideas in research on teaching and learning in engineering and our interview participants' familiarity with equity scholarship, we saw numerous alignments among themes in literature and our interview findings. Supported by concept mapping we did to categorize literature we read, we next used crosswalk analysis (e.g., [20]) to link concepts and ideas in the literature with specific interview findings., The course content and instructional practice codes from our interview data analysis informed the current iteration of our curricular and instructional framework. Specifically, the instructional codes identify and group ways that instructors could center equity in engineering classrooms, offering a variety of illustrative examples in different course contexts (e.g., using sociotechnical content to center equity, engaging students in active learning to teach equity content; see [19] for more information regarding course content). We use the term "illustrative examples" to indicate that these are examples and not the only ways to teach equity in engineering.

Phase IV: Concept mapping and organizing around the principles

To further develop our framework beyond a list of practices identified through our interviews and analysis, we again used concept mapping, to connect the course content and instructional practices to the principles mentioned above (Phase 4; see Fig. 1). These principles became a useful central organizational tool, since during our analysis of the literature and interviews, we continually saw alignment with the principles. We also iterated on the principles to clarify them throughout this process. In finalizing the principles, we revisited and continued our literature review, this time focused on each principle individually.

In the next section we present our six principles of equity-centered engineering curriculum and instruction, and provide supporting literature and illustrative examples from the interview data. To be clear, the principles and the framework overall are intended to serve as a guide to equity-centered engineering curriculum and instruction that instructors can apply in ways that fit their subject matter, context, and pedagogical approach. After overviewing the six principles and discussing cross-cutting themes, we will briefly describe further steps for the development of our framework and remaining elements.

Principles of equity-centered engineering curriculum and instruction

The six principles can be divided, for the purpose of discussion, into two subsets, as shown below, with principles one through three more focused on curriculum and principles four through six more focused on instruction. As such (see also earlier version of principles in [19]):

Equity-centered engineering curriculum:

(1) embeds a *sociotechnical view* of engineering that consistently counters views of engineering as neutral, objective, or decontextualized;
(2) emphasizes instructors' and students' ongoing *reflection* on (in)equities and one's role and positionality in engineering practice now and in future engineering work;
(3) uses an *equity lens* to examine processes and outcomes of engineering, including consideration of past and present (in)equities, and influences of identity, power, privilege, and culture;

And, equity-centered engineering instruction:

(4) intentionally cultivates and facilitates an *equitable learning environment* - which is characterized by equitable interpersonal interactions - that enables students' and instructors' learning and affirms students' social identities and sense of belonging;
(5) *equitably assesses* students' learning of course content, including the use of multiple assessment modalities; and
(6) *assesses* students' developing understanding and capacity to engage in *equity-centered* engineering practice.

This distinction between curriculum and instruction is a pragmatic choice; in reality, the two cannot be entirely disentangled. The numbers assigned to each principle provide a shorthand reference and are not intended to suggest an order or hierarchy to the principles. However, the principles do interact, mutually support, and potentially build upon each other. For example, we posit that teaching engineering content as centered around equity and social impacts is facilitated by an equitable classroom environment; and vice versa, teaching equity-centered engineering supports the creation and maintenance of an equitable classroom environment.

We begin our discussion of each subset of principles with a brief overview and then provide a focused discussion of each of the three principles in that subset.

Curricular principles

The content-focused principles in our framework, Principles 1 through 3, call for the integration of sociotechnical and equity-focused content to support ongoing reflection of engineers' positionality. They also call for attention to the inequities that can result when engineers and engineering decision-making do not attend to past and present inequities and the role of power. Principle 1 focuses on sociotechnical integration in engineering education, which affords opportunities for using equity lenses (Principle 3), supported by and supporting engineering students' and instructors' self-reflection (Principle 2). These are important ways to support diverse participation in engineering and authentically prepare students for engineering work.

Principle 1: Embeds a sociotechnical view of engineering that consistently counters views of engineering as neutral, objective, or decontextualized

This first principle promotes the development of courses that not only introduce a sociotechnical view of engineering practice, but consistently integrate it in order to counter perspectives of engineering as neutral, objective, or decontextualized. Smith et al. [21] identified four different lenses of engineering regarding the social and technical dimensions; three of those consider the social and technical as separate aspects, though potentially related or interacting. Only the fourth lens achieves full sociotechnical integration. Reddy et al. [22] define integration as:

> "Social and technical dimensions of a given phenomenon are not only mutually shaped, but are fully mutually constituted: One cannot exist without the other, conceptually or materially. Independent constructs of social and technical are misleading simplifications, since each is necessarily and inexorably intertwined with the other" (p. 5).

Rationale for Principle 1

Presenting engineering as authentically sociotechnical responds to certain stereotypical views of engineering that uphold a problematic engineering culture and impede attention to social impacts, excluding students interested in the social impacts of engineering. These include:

- the belief that engineering is meritocratic, value-free, and politically neutral ([23], [24] - [31]);
- prioritization of technical knowledge over social understanding ([18], [23], [24], [28], [29], [32] - [36]);
- engineers' positivist epistemology, "hidden under the auspices of 'rigorous' research" ([37] p. 40; [38]);
- decoupling of ethics and equity in engineering education research and practice [12];
- and a culture of disengagement [39].

The impact of these normative beliefs and practices results in students prizing "technical" courses and considering others less useful. Downey [40] reported that students tend to rank their courses in a hierarchy of importance, with "core" engineering courses, focused on "technical problem-solving" highest, then design, then humanities (p. 588). This pressure to have a strong technical background can prevent students from "fully identifying as engineers and create discomfort with ambiguity and open-ended problems" ([36], p. 15).

Sociotechnical integration

Thus, to effectively counter these inauthentic and exclusionary elements of engineering culture, instructors must not only present engineering as sociotechnical, they must engage students with this idea in a variety of engineering courses so that students experience repeated touchpoints throughout their academic paths. In their study of the introduction of sociotechnical course modules, Gelles and Lord [29] learned that it was necessary to interweave sociotechnical content in a course and include assessment questions on the sociotechnical module content to message to students the value of this content. Claussen et al. [32] similarly suggest revisiting sociotechnical assignments across the years of students' curriculum. Our interview participants similarly discussed instructional practices they used supporting this principle, like the importance of not compartmentalizing equity and social impacts as separate from the technical work of engineering, as has often happened with ethics education. One participant specifically said,

> "My experience has been when we try new things and students are uncomfortable, when we get them into a pattern, a rhythm of expectations, when they know that this is what class is going to look like, …they become comfortable. They're fine with it. It's when we balk and we say we're going to do sociotechnical thinking, and then it disappears in the middle of the semester. …When you don't manage their expectations, things can go off the rails."

The full integration, mutual shaping, and inability of the social or technical to exist without the other [22] has important implications. Presenting engineering as authentically sociotechnical involves treating the social implications and impacts of engineering as a central element of engineering work. On the other hand, attempts over the years to "broaden" engineering – with sociotechnical elements under that term "broadening" – can lead to views of sociotechnical dimensions as separate from true engineering. As Downey [40] says,

> "To focus on broadening may be to lose the battle at the outset because it preserves a distinction between technical core and non-technical periphery. If successful engineering practice has always involved more than technical problem solving, …the challenge today is not to broaden it but to rethink and redefine its core" (p. 584).

In short, separating or tacking on discussions of the social impacts of engineering will continue to maintain the social-technical divide; "broadening" engineering is not sufficient ([11], [26], [32], [36]). Indeed, in sociotechnical-focused courses, the social-technical divide still often persists for students, reinforcing the need for integration. In Gelles and Lord's study [29], students struggled with valuing sociotechnical content compared to the strictly technical content they expected in an engineering course. Johnson et al. [23] studied a control systems engineering course, of which one section had a social justice intervention. They saw mixed outcomes. Students sometimes expressed that social factors are relevant to engineering, but did not necessarily see them as part of engineering; particularly, "many students reported the difficulty of switching gears between social and technical considerations" ([23], p. 6).

Sociotechnical skills are not only inherently important for engineering students entering the workforce [41], but connecting topics to real-life situations also supports student understanding of engineering and is something students often want ([23], [42]). Thus, embedding a sociotechnical view of engineering supports equity-centered engineering education by countering problematic engineering cultural norms, affording opportunities to prompt reflexivity, and highlighting the relevance of equity considerations in engineering – which may help broaden participation in the field. Teaching sociotechnical engineering has been shown to support the interests and persistence of students from minoritized identity groups ([1] - [3], [24], [25], [33], [43] - [45]), a longstanding aim of engineering [37], which also serves to benefit the performance of engineering teams [46]. Reddy et al. [22] further argue that sociotechnical approaches to teaching engineering have other benefits, including "enhancing student engagement, addressing ABET learning outcomes surrounding the understanding of context, [and] supporting students' ability to engage ambiguous open-ended problems with attention to diverse stakeholders" (p. 3).

Illustrative examples of Principle 1 in practice

Despite the persistence of the social-technical divide in students' thinking, sociotechnical engineering courses, workshops, and modules have had success at developing students' sociotechnical understanding and skills (e.g, [23], [29], [47]). Engineering instructors can challenge the social/technical dichotomy by framing engineering as a set of non-neutral activities, thus helping students to think about neutrality problems in engineering classrooms and workplaces [48]. In an "interdisciplinary Engineering Studies degree program", consisting of a "core course sequence [to] give students an …identity as sociotechnical engineers" ([1], p. 2), Rossmann et al. found that students' autobiographical essays in their capstone experience showed that they gained contextual understandings of human impacts and an appreciation for the sociotechnical nature of engineering. In a Civil and Environmental Engineering Department, Andrade and Tomblin [49] studied a required sophomore-level Engineering for Sustainability course, which incorporated the social dimensions of sustainability. They focused "on the challenge of integrating macro-ethical sociotechnical thinking skills through stakeholder value mapping" (p. 2), and found that the mapping exercises helped students articulate and identify nuanced and complex social impacts of technology [49]. Thus, there have been successes at developing students' sociotechnical thinking through engineering courses.

In our interviews, participants described many ways to teach sociotechnical engineering that opened up questions of equity, including sharing examples of soap and paper towel dispensers that do not recognize dark skin; the potential damage of AI and who is impacted; biased algorithms; bridges that are not tall enough for public transportation to pass under; college campuses designed to limit protests; and impacts of Tesla lithium mining on indigenous communities. Similar examples in literature include: challenging statistical objectivity in data science by discussing eugenics [50]; impacts of single-use plastic straws and considering both sustainability and accessibility [29]; and racial bias of pulse oximeters [51].

Interview participants also discussed teaching content that prompts students to think about diverse human users in their own design work. Interviewees talked about partnering with local or global communities for students to design something useful to real users; posing questions to students including how their designs would change for different users (e.g., non-native English speakers, different ages); and having students design playgrounds for users in a cold location. Similar examples from literature include: having students design playground equipment for children with disabilities [52]; and teaching students to ask equity-centered questions about the potential users of their designs ([18], [53]). Thus, there are a number of examples to spark ideas of ways to implement this first principle in engineering courses.

Furthermore, centering equity in engineering can promote a contextualized view of the field and its practices by challenging views of engineering knowledge as apolitical, ahistorical, or neutral (see [54]). This challenging of engineering cultural norms involves self-reflexivity, connecting this principle with Principle 2.

<u>Principle 2: Emphasizes instructors' and students' ongoing reflection on (in)equities and one's role and positionality in engineering practice now and in future engineering work</u>

This second principle includes two elements: (1) instructors' self-reflection on their positionality as engineers and as instructors; and (2) instructors' encouragement of students to reflect on their own positionality as engineers.

Instructor reflection

For instructors, The Center for Research on Learning and Teaching at the University of Michigan provides a definition of self-reflection:

> "[Self-reflection] refers to the process of examining your own background, identities, and life experiences. These influence your actions, beliefs, and perceptions and expectations of others – such as your students. As an instructor, self-reflection is a tool that can help you identify how your teaching practices and classroom policies unknowingly perpetuate systemic inequities" [55].

Other scholars think about this practice as "continuous and critical reflection about the broader social consequences of one's practice, which requires the ability to become increasingly aware of biases, and to be willing to investigate the ways internal perspectives inform our interactions, relationships, and behaviors" [28]. Hancock and Turner [6] argue for the importance of "engaging with our positionality" and "taking into account the power of engineering education institutions to indoctrinate engineering culture" as elements of their engineering social justice praxis (p. 5). Several authors argue that instructors need to reflect on their positionality to effectively implement equity-centered pedagogy ([56], [57]). Instructors' personal experiences and identities impact their research, praxis, and ways of educating [58]; similarly their understanding of engineering intersects with their personal experiences and identities. Through self-reflection, instructors become aware that their constructed perception of social justice and engineering is impacted by their own cultural norms and lived experiences [6]. Leydens et al. argue that traditional engineering epistemologies assume apolitical, neutral, and bias-free knowledge by focusing on efficient and interdependent functionality [59]. Instructors' self-reflection can support challenging this dichotomy, since knowledge production is always situated in socio-political contexts. Thus, this principle both supports an equitable and inclusive classroom environment, as well as the integration of sociotechnical and equity-centered course content (showing its interaction with Principles 1 and 3).

There is a growing body of scholarship on how to promote instructors' self-reflection. To begin, scholars have argued that the initial step is instructors' critical reflection on their social identities, such as race, class or gender. This supports instructors' increasing awareness and prevention of "seen, unseen, and unforeseen" biases ([60], p. 1). This is important to consider for an equitable classroom environment, since students of different social identities than their instructors may face difficulties voicing questions or disagreement in engineering classrooms [61]. Additionally, Kishimoto proposed that self-reflection should begin before instructors go into the classroom and be continuously revisited alongside and throughout the teaching process [54]. Equity-centered pedagogy emphasizes life-long learning. Instructors should engage in the ongoing process of metacognitive reflection and adhere to a conscious commitment to personal transformation [24]. Riley [62] adds that instructors should carefully consider their course content, focusing on elements like the syllabi, materials, activities, and curriculum; Riley encourages liberative pedagogies, involving “relating course material to students’ experience” (p. 144) and treating “students as authorities in the classroom” (p. 147), since “ignoring oppression doesn’t work” (p. 141).

To support the process of instructor reflexivity, Beverly and Gillian-Daniel [63] write about the Inclusive Professional Framework (IPF), which “center[s] a reflective process, which in turn leads to self-reflexivity” (p. 1). Dewsbury [64] also suggests an adapted version of a “privilege walk” [65] as a professional development activity to foster “deep reflection on social inequities” (p. 1).

Student reflection

It is also important to prompt and guide students to reflect on their own positionality as current and future engineers. Similar activities to these instructor-focused activities can also be used for students (e.g., [12] used the invisible knapsack in a curricular intervention), and to effectively teach such course content requires instructor reflexivity. These points both show the link between the student and instructor elements of this principle.

Regarding student reflexivity, Agresar et al. [28] argued that in order to develop an equity-centered classroom, students should "express and critically reflect on how their identities, background, experiences, biases, privileges and disadvantages influence their engineering education, practice, and teamwork." (p. 7) This may help students, especially underrepresented students perceive the classroom climate more positively, which can be a motivator for them to complete engineering degrees [66]. Without student self-reflection, students may have a biased understanding of engineering, reflecting how students unintentionally internalize social constructs and norms [67]. Effective equity-centered education also benefits students from various backgrounds, developing their cognitive and affective understanding of the complexities of equity-related issues [68].

Illustrative examples of Principle 2 in practice

Our interview analysis revealed discussion of the instructor practice of self-reflexivity and course content on student reflexivity. First, participants offered interesting insights into instructors’ self-reflection. They believed instructors should deeply consider their positionality and power in educational settings, including reflection on their background and previous experiences and how that equips or does not equip them for their current teaching. This involves reflecting on what they have learned from their own previous educational experiences, as well as on the ways they will actively take up or reject power as teachers. One participant said,

> “My students… are very well aware that I think it's a bad thing that I have so much power over them. I take concrete efforts to hand over power back to students and reject my own power. Part of that is explaining to them why they can call me [by my first name]. A big part of any equity-centered pedagogical practice would be allowing students the agency to understand, to deserve an explanation of why I'm making a decision that I am and offering them the time and space for them to counter my decision. For me, that means that if I'm going to change a structure for the class, or implement a structure for the class, I explain to them exactly why I think that structure might be helpful and then I let them alter it, reject it.”

The participants also discussed framing students in anti-deficit ways, having empathy for their students, and examining their own teaching and changes within their control before blaming students for low academic achievement or performance. As for course content prompting student reflexivity, participants discussed teaching students to reflect on their own identity, previous experiences, positionality, biases, and power, as they relate to students' future engineering practice. For example, interview participants talked about assigning students to take implicit bias tests and write reflections on them (without the requirement to share their test results) (e.g., see [14]). Instructors also noted their important role in encouraging students' reflection, particularly in cases where they got to know their students well and built connections with them (e.g., by sharing about oneself with students). For this relationship building, one interview participant described her strategy of asking students to "tell me something I don't know" and sharing some responses in brief slides once per week of class. This approach shows that relationship building between instructors and students, as well as students and their peers, can be supported even in large classes. Building community supports and is supported by individuals' reflexivity.

This principle, highlighting the importance of instructors' and engineering students' reflexivity, when paired with Principles 1 and 3, supports students to engage in engineering practice considering impacts on equity.

Principle 3: Uses an equity lens to examine processes and outcomes of engineering, including consideration of past and present (in)equities, and influences of identity, power, privilege, and culture

This third principle builds upon Principle 1 by going beyond a sociotechnical view of engineering to explicitly center equity. By an equity lens in engineering, we mean centering discussions of engineering impacts on marginalized people and communities by considering who (in)equitably benefits or is harmed by engineering work, and striving to achieve parity of access, opportunities, conditions, and resources for diverse groups of people through engineering work. This leans on Posselt's [69] definition of "equity work as reconfiguring structures, cultures, and systems to empower marginalized groups and close disparities" (p. 2). Within engineering specifically, Agresar et al. [28] propose that "equity-centered engineers are not only technically competent, but they must also understand and work to ameliorate the historical and systemic patterns of disparities in society" (p. 3). Similarly, Gallimore [70] argues,

> "[W]e need engineers to be aware of and correct for the ways their work unwittingly impacts the distribution of wealth, power and privilege in society. We need to first acknowledge who benefits and who is harmed. And after engineers understand that, we need to approach the work with an intent to close—rather than unintentionally expand—these societal gaps by ensuring equitable access to opportunity" (p. 1).

Connections between Principle 3 and Principle 1

This idea that engineers have a responsibility as part of their work to consider and strive for equity and to understand the landscape in which their work is situated and the impacts thereof is a growing idea in literature (e.g., [1], [6] - [8]). It builds upon the concepts of sociotechnical engineering from Principle 1. Sociotechnical content is not necessarily equity-centered and does not inherently involve taking an equity lens, but highlighting and emphasizing the social context and impacts of engineering affords opportunities to implement this principle. For example, as we saw in the section on Principle 1, a sociotechnical example that an interviewee used in a course was bridges that are not tall enough for public buses. When we dig into this case further, opportunities for discussion of (in)equity arise, given that public transit users may be of a lower socioeconomic status or from minoritized racial groups compared to the demographic makeup of the city overall; such bridge design would inequitably impact residents' access to areas of the city. Thus, bridges too short for public transit not only illustrate the sociotechnical nature of engineering, but also the impacts of engineering on (in)equity. In this way, sociotechnical content can afford opportunities to use an equity lens to examine engineering. Engineering content focused on equity and justice can also support sociotechnical thinking; for example, Leydens and Lucena [9] discuss how "rendering social justice visible" in engineering support students' ability to identify sociotechnical connections (p. 7).

Indeed, it may be easier to ensure that students think about engineering sociotechnically than to promote the use of an equity lens and understand and examine structural dynamics. Even in a course focused on social justice in engineering [23], students were more comfortable thinking about "reducing imposed risks and harms" (p. 3) than understanding and identifying structural conditions. Similarly, in a learning activity focused on energy justice [71], authors reported that students were more capable of recognizing the existence of injustices and power dynamics in engineering work than considering the "source of the problems (e.g., racism, imperialism, colonialism)" (p. 84).

However, we can imagine that the same arguments for increased sociotechnical integration (e.g., [29], [32]) also apply to the necessary ways of centering equity and justice in engineering education. In other words, with more touchpoints across a students' academic journey, we would expect to see success in students' developing capability to identify and consider structural conditions and take an equity-centered view of engineering. As we have seen earlier, scholars discuss sociotechnical content as affording opportunities for content on equity and justice, and vice versa (e.g., [9], [23], [71]). In such interventions, researchers saw mixed results for students, typically with more success in developing students' sociotechnical thinking and less success developing students' capability to identify and consider structural conditions, like racism.

Illustrative examples of Principle 3 in practice

Other course content discussed in our interviews that would support this principle includes: course content about the engineering context, and course content prompting student reflexivity (some examples of this already mentioned in the section on Principle 2). Regarding the engineering context, our interview participants included discussion of student and faculty demographics in engineering as well as the different populations with whom people in engineering interact depending on the context; the contextual reasons and explanations for those numbers and demographics; comparisons of national and institutional statistics; and engaging such data in conjunction with activities like privilege walks or implicit bias tests. Such course activities support taking an equity lens toward examining the engineering and engineering education context, including the people who participate in engineering (see also [52]).

Echoing arguments regarding the challenges of integrating sociotechnical content into "technical" courses, scholars also argue that it is easier to integrate an equity lens in engineering into some courses than others. Many of the examples are in the context of design (e.g., [72]). Rottmann and Reeve [12], for example, state, "It is easier to integrate ethics and equity issues into complementary studies than technical courses" (p. 162). Das et al. [53] offer a framework for Engineering Equitable Design and Equitable Design Research that builds upon

Costanza-Chock's [73] Design Justice framework. Notably, it includes engineering equitable design questions such as:

> "Who is included in the design process as a co-designer? How can we incorporate people and communities into the design processes through participatory techniques such as participatory design, co-design, or citizen science? What is the background and identity (race, socioeconomic class, ethnicity, gender, disability, and sexuality) of those who are included in the design process? What backgrounds and identities are not represented? Who is regarded as an expert and why?" ([53], p. 11).

Course contexts: Engineering design, science, and ethics

Relatedly, Waight et al. [74] call for increased transparency in the black box nature of technology, raising a set of tenets for equitable, social justice criticality in technology (p. 1507). They discuss the intersection of science and technology as complex and in flux, suggesting that divisions between engineering science and design are complicated and sometimes arbitrary. Thus, though many agree that it is easier to integrate equity topics into the design context, the divisions may be more malleable than expected (see also [18], [19]).

Furthermore, engineering ethics education is also viewed as an easier place to use an equity lens ([12], [75], [76]). In a systematic literature review, Hess et al. [75] investigated how ethics and DEI are explicitly connected in engineering education literature. They found that authors have used (1) social, (2) justice-oriented, or (3) professional lenses to connect DEI and engineering ethics. Social lenses included "prompting students to consider social implications" (p. 150) of engineering (e.g., [77] - [79]). Justice-oriented lenses involved framing "justice as an aim …of engineering practice" (p. 151) (e.g., [80], [81]). Lastly, the professional lens involved framing "being a professional engineer [as] requir[ing] one to consider ethics and DEI connections" (p. 151) (e.g., [82], [83]). Hess et al. [75] also provide examples of authors' engagement strategies for students to connect ethics and DEI, e.g., working in diverse teams and understanding diverse stakeholders. Though some studies have found mixed results for students' experiences in equity-centered courses, students seem to appreciate and be interested in issues of equity. Rottmann and Reeve [12] found that students considered an ethics and equity workshop to be "more practical, relatable, authentic, engaging, and helpful when grappling with ambiguity" than their previous ethics education (p. 154).

In short, these first three principles implemented in courses would teach students sociotechnical, reflective, and equity-centered engineering content, skills, and processes.

Instructional principles

The instruction-focused principles in our framework, Principles 4 through 6, call for equitable classroom environments and equitable teaching practices to support equity-centered engineering education. As we noted earlier, curriculum and instruction are mutually reinforcing; they must be jointly considered to achieve equity-centered engineering education. Additionally, intentional planning of the learning environment is necessary due to the strong emotions and tensions that can arise in discussions of equity. Furthermore, Principles 5 and 6 conceptually follow Principle 4. Although they are aspects of an equitable classroom environment, they warrant individual attention as distinct teaching practices. Moreover, assessing equity content (Principle 6) is an important way of messaging to students the value of that content.

Principle 4: Intentionally cultivates and facilitates an equitable learning environment - which is characterized by equitable interpersonal interactions - that enables students' and instructors' learning and affirms students' social identities and sense of belonging

Students need opportunities to practice solving authentic problems, and this includes attention to the social context in which engineering work occurs ([18], [84]). Our first three principles argue that this should involve having students actively reflect on the role of engineering in contributing to societal (in)equity and construct their understanding of engineering as a sociotechnical discipline. This necessitates active processes of learning ([18], [29], [85]).

Active and collaborative learning and equitable instructor-student interactions

While active learning that is also collaborative inherently creates opportunities for interactions amongst students and instructors in the classroom, additional work is necessary to ensure these interactions are equitable. In addition to the role of instructor as facilitator discussed above, classroom norms are helpful to support equitable interactions and mitigate harm, particularly during discussions centered around equity. Previous literature outlines examples of classroom norms and strategies for supporting multicultural group dynamics (e.g. [24], [28], [86]). Similarly, all of the instructors we interviewed in our study described using some form of collaborative learning in their courses, particularly when teaching sociotechnical or equity content. They found collaborative learning had affordances for integrating equity considerations into the content of their courses because it provided informal opportunities for discussions of equity to arise and because collaborations could be used to prompt students to consider diverse perspectives.

However, participants also acknowledged the potential harm that can occur during student collaboration, and reinforced the use of norm-setting to foster equitable interactions. They provided examples such as co-constructing guidelines for classroom discussions with their students and creating team contracts that set norms for engagement during group projects. For example, Rottmann and Reeve [12], in discussing their curricular intervention aimed at bridging the equity-ethics divide in engineering, conclude with suggestions of how to support respectful student-student and student-instructor interactions, including ground rules for respectful disagreement. Similarly, the Center for Research on Learning & Teaching at the University of Michigan [13] provides guidelines for responding to hot moments, i.e. a "sudden eruption of tension or conflict in the classroom", which can occur during discussions that are challenging and/or potentially controversial such as those around equity (e.g., [14] discusses student resistance to racial equity content in a physics course).

In creating an equitable learning environment, it is additionally important to validate students' previous knowledge and lived experiences, uplifting these ways of knowing as valuable sources of knowledge in the engineering classroom ([36], [71], [87]). In his introduction to the knowledge in pieces framework, diSessa [88] argues that while students may have different forms of knowledge, all are important for building understanding. He illustrates how educators can build on students' rudimentary ideas in ways that honor the richness and diversity of their knowledge.

Illustrative examples of Principle 4 in practice

Our interview participants similarly highlighted the importance of equitable instructor-student interactions, emphasizing the role of instructors' continual self-reflexivity on their own identities and how those may differ from their students' identities, as discussed in Principle 2. Participants described pushing back on the traditional authority structures in their classrooms, such as being willing to tell students when they did not know the answer to something and thus positioning themselves as a learner in the classroom, which was one way in which they worked to foster more equitable instructor-student interactions. One participant said,

> "I'm even learning from my students that part of that being afraid to say, 'I don't know,' is basically a hidden epistemology of engineering. We're not supposed to say, 'I don't know.' And that is also something that I'm intentionally trying to dismantle… None of us know it all. There is a limit to what all of us know. So at some point in your career, a student or a colleague or someone is going to challenge you and ask you something that you flat out do not know. And guess what? It's okay. The world is not going to spin off its axis. Gravity will not stop working. So it's becoming more comfortable with that discomfort."

This principle explicitly acknowledges the importance of affirming students' social identities and sense of belonging. There is an expansive literature on the role of sense of belonging in supporting retention and success in college, as well as in shaping students' educational and career aspirations (e.g. [89], [90], [91]). Strayhorn [90] describes how sense of belonging is intertwined with students' social identities including race, gender, and sexual orientation. Scholars often attend to sense of belonging in their recommendations for inclusive and equitable teaching; for example, in their framework for inclusive teaching, Dewsbury and Brame [92] affirm the linkage between instructors' pedagogical choices and students' sense of belonging.

In short, this principle argues for an equitable classroom environment as a necessary piece of teaching equity-centered engineering. The following two principles give more details on assessment as an element of an equitable and equity-centered classroom.

Principle 5: Equitably assesses students' learning of course content, including the use of multiple assessment modalities

Teaching and assessment practices are shaped by disciplinary norms, values, and beliefs that advance or deter equitable learning [93], and instructors' conceptions of underrepresented and minoritized students in assessment can affect equity outcomes [94]. Faculty who endorse fixed mindsets about intelligence may approach examinations, assignments, and grading as gatekeeping strategies that measure and rank student learning outcomes ([95], [96]). These views can have significant and negative impacts on students, particularly minoritized students in STEM, including lower academic success, persistence, and sense of belonging ([96], [97]). Challenging the use of conventional assessments in STEM education, Wiggins [98] argues that authentic assessments benefit learners (i.e., "attend[ing] to whether the student can craft polished, thorough and justifiable answers, performances or products" (p. 1), as opposed to conventional tests that only ask for correct responses).

Give students opportunities to express their knowledge in a variety of ways

In STEM education, equitable assessment involves taking stock of (in)equities in assessment and grading practices that stifle achievement outcomes. This includes interrupting reliance on conventional high-stakes summative testing and other tough-love assessment approaches that reify exclusionary and meritocratic norms, result in negative well-being and stress in test-taking, and ultimately deter minoritized students' persistence in STEM fields [96]. One strategy to counter conventional approaches includes the use of multimodal assessments that provide multiple opportunities for students to demonstrate their learning and express their understanding in a variety of ways ([45], [99]). Multimodal assessments (a) build upon students contextual knowledge to foster sense-making, (b) align with active and collaborative learning practices, (c) advance multiple and alternative ways of knowing, and (d) encourage multiple solutions and avenues for students to receive and interpret course content [45].

By centering learners' knowledge, multimodal assessments create varied means to demonstrate mastery of knowledge and skills, empowering students to apply their strengths ([45], [100]). Participants in our study described how varied assessments including critical reflection papers, project-based exercises, group exercises, case studies, and other approaches that include feedback loops and opportunities for resubmission reduced grading anxiety among learners and promoted opportunities for growth in learning. One instructor describes the "low stakes environments" they try to create through low-stakes early assignments:

> "We do a lot of staged assignments or staggered assignments where they do an initial, they get feedback, it's worth less points, and then they submit a final resubmission where students submit things and then they can resubmit oftentimes for full credit, and all but one of my classes that I've taught have no tests, so no exams, it's all project-based or small assignment based things."

Such approaches reflect equity orientations to assessment that can be applied in project-based engineering courses as well as large enrollment courses.

Broadly, Henning & Lundquist [101] argue in their equity assessment conceptual framework that equity-minded assessment involves educators who:

> "acknowledge the history of oppression and colonization within which assessment is being conducted; recognize and move to interrupt inequitable systems; investigate and discuss who decides and benefits from assessment; consider how value is attached to what is measured; critique how meaning is attached to data and results; and recognize and address the extent to which their assessment work prevents structural transformations and equity" (p. 188).

Evaluating students' application of critical reasoning or imaginative learning, rather than testing their recall alone, provides more accurate evaluations of their problem-posing and problem-solving skills. Moreover, student-centered and formative assessment practices can promote positive academic motivation and student agency [102]. These practices promote equitable assessment of student learning, as well as the use of varied opportunities for students to demonstrate knowledge or mastery ([45], [100], [103]).

Connections between Principle 5 and Principle 2: Instructor reflection on assessment

In our study, one participant who worked in a teaching and learning center described their approach to training engineering instructors to teach diverse classrooms by challenging conventional engineering assessments and incorporating assessment strategies that gauge and promote learning development overtime. She explained:

> "When we talk about the history of the paper pencil test and the assessment and the actual measurements, that allows me an opening to talk about equity and how we as teachers can constrain student learning…. My go-to for opening up any lesson plan is a guiding question, whereas I open a lesson with an actual question and tell them that they can come back to that same question at the end of the lesson, and then it could be used as a small formative assessment. So how do students answer the question at the beginning? How do they answer the question at the end?"

Instructors' intentional efforts to challenge fixed mindsets, beliefs, and conceptions of the purposes of assessment is vital to equitable outcomes in academic achievement. In a study on the relationship between instructional beliefs and student academic achievement in undergraduate STEM courses, Park et al. [96] concluded that "students taught by STEM faculty who held fixed mindset beliefs earned lower grades and experienced larger equity grade gaps relative to students in courses taught by STEM faculty who held growth mindset beliefs" (p. 883). In contrast, students received higher grades and equity grade gaps improved among minoritized and underrepresented students when enrolled in courses taught by instructors who centered students' voices and included equity discussions in their STEM curriculum [96]. Other evidence in the literature suggests that centering the knowledge and assets of students in assessment promotes more equitable learning experiences and outcomes [104]. At the same time, diversity, equity, and inclusion education scholars agree that holistic alignment between curricular, pedagogical, and assessment approaches that invite minoritized student's experiential knowledge and assets are vital to creating equitable learning environments ([24], [94], [101], [105]).

Illustrative examples of Principle 5 in practice

Though few studies in engineering sciences address specific strategies that promote equitable assessment, Farrell, Godwin, and Riley [24] argue that instructors who communicate and clarify the relationship between assessments and the intended learning goals and objectives of engineering content foster fairness and equity in classrooms. Farrell, Godwin, and Riley's [24] sociocultural learning framework for inclusive pedagogies posits that instructors who convey alignment between pedagogy and assessment promote inclusive learning environments and expose or make explicit the hidden curriculum. One empirical example in engineering education includes a case study of the use of liberatory pedagogies in an undergraduate thermodynamics class. Using narrative web blog entries to "encourage self-assessment and metacognition" researchers examined how the integration of liberative pedagogies in course design aligned with reflexive assessment practices fostered students' critical thinking and reflective action [106].

In our study, participants described how their mindsets and approaches to assessment in technical engineering courses take into account students' different learning paces, including variable exposure and experience in engineering. To promote inclusive and equitable learning experiences, these instructors include multiple opportunities for students to demonstrate academic progress and achievement, as well as mastery of technical course content. Below, an instructor describes how her continuous assessment and grading approach aids students to persist in learning technical curriculum:

> "Deconstructing our entire system of assessment toward equity is not a one-step thing. A starting point that I'm working on, that I think a lot of instructors could also work on, is what does zero stakes assessment look like? My students essentially have 0% stakes for 100% of the semester. What that means is that for every learning outcome, I need them to

show me that they understand in order to pass a technical subject and move on and be ready. I'm confident I can send them to the next class, and they got this, so they've passed the class. I don't care whether they master that on day one or the last day of the semester. There's no impact on their grade… That's what equity looks like is that you can learn at a different pace."

This zero-stakes approach to assessment includes multiple opportunities for students to learn course content and thus seeks to remove barriers to learning and promote students' academic progress. Another way that instructors reduce barriers to learning includes prioritizing student voice in course policies and procedures [107]. In our study, some instructors sought to facilitate learning by giving students decision-making power in grading, rubrics, and assessment formats. These practices were intended to promote equity in achievement, as well as independent and critical thinking in engineering sciences. For example, one instructor describes the importance of flexibility in grading, saying,

> "One of the things that I did when I did have control over the curriculum, particularly for graduate students, I would let them pick their own final assignment. They got to decide what the format of their final assignment would be. And again, that is engaging them in their own learning."

Taken together, equitable assessment involves countering conventional assessment strategies with formative approaches that center student voice, experience, and assets and embrace longitudinal and developmental perspectives of learning.

Principle 6: Assesses students' developing understanding and capacity to engage in equity-centered engineering practice

This principle calls for instructors to assess students' ongoing learning and ability to engage in equity-centered engineering practices. By evaluating students' understanding of equity and sociotechnical content, instructors underscore the significance of equity-centered engineering work and help students recognize the inherent role and value of equity considerations in engineering.

Examples of sociotechnical assessment

As mentioned in the section on Principle 1, Gelles and Lord [29] discuss the importance of incorporating sociotechnical content into course assignments and assessments as an effort to introduce students to the social and contextual nature of engineering work. This works to normalize sociotechnical material in engineering courses so that students come to understand that it, too, counts as engineering. Gelles and Lord [29] state, "With this revised sociotechnical engineering canon, students will be able to approach problems with an expanded lens where they understand how social contexts and technical problems shape each other" (p. 1245). Additionally, the incorporation of sociotechnical material in engineering courses helps to pave the path for other equitable engineering pedagogical choices by presenting engineering as authentically and inherently equity-centered and thus changing the norms and expectations to center considerations of equity.

The shift toward equity-centered engineering education aligns with research that highlights the role of sociotechnical thinking in addressing diverse societal challenges [24]. Fajardo et al. [108] developed a framework for assessing students' sociotechnical thinking and provide evidence that sociotechnical thinking strengthens students' capacity to engage in equity-centered engineering by promoting social awareness. This can further shape their identities as engineers committed to equitable impact [34]. Similarly, Claussen et al. [32] illustrate how students' perceptions of social and technical dimensions influence their engineering identities. This perspective promotes equity-centered practices, as students begin to recognize the impact of engineering solutions within broader social contexts.

Assessment tools designed to capture sociotechnical habits of mind are crucial for promoting equity-centered engineering practices. Johnson et al. [109] developed a survey to assess these habits, which reflect a balance between technical expertise and social awareness. Results from this survey revealed that students exposed to sociotechnical content reported a greater awareness of the broader societal implications of their work, which emphasized the importance of assessments that extend beyond technical skills to include socio-ethical engagement. Likewise, Leydens and Lucena [18] validated models for tracking changes in sociotechnical thinking, highlighting the transformative impact of continuous exposure to equity-centered curricula on students' engineering identities. Another example of a tool that has been developed is a rubric from Mazzurco and Daniel [110] for scenario-based assessments on open-ended, contextualized problems. Tools assessing related concepts like critical consciousness and critical reflection skills could also be relevant (e.g., [111]). This suggests further interconnectedness between our principles as this principle involves assessing students' sociotechnical learning (Principle 1), reflection skills (Principle 2), and equity-centered engineering learning (Principle 3).

Connections between Principle 6 and Principle 5

Inclusive assessment strategies are also essential for accurately evaluating students' sociotechnical understanding, highlighting how this principle interacts with Principle 5. Paguyo, Sponsler, and Iturbe-LaGrave [112] advocate for assessments that recognize diverse learning experiences and identities, which aligns with Dewsbury and Brame's [92] recommendations for creating equitable assessments that address biases. For accurate assessment of students' sociotechnical understanding and learning, it is necessary to recognize and account for diverse learning experiences and identities. Foley, Ferguson, and Pollack [47] suggest using concept maps as assessment tools to capture students' comprehensive and sometimes non-linear understanding of sociotechnical issues, offering a nuanced perspective on their development in equity-centered engineering practices. Castillo-Montoya and Madriaga [113] add that decolonizing assessments by moving away from "colonial, neoliberal, hegemonic (often Western and Eurocentric) 'modes of knowledge production" (p. 2) allows a broader range of student experiences, particularly those of women and students of color, to be validated (see also [114]). This can enrich the quality of learning in sociotechnical and equity-centered engineering education. Castillo-Montoya and Madriaga [113] discuss such ideas as "assessing how students regularly critique and probe the positionality of knowledge" (p. 3); "assessing how students expand in their understanding based on an inclusive curriculum" (p. 4); "assessing how students are prepared to engage in relational teaching and learning" (p. 6); and "assessing how students connect with communities and sociopolitical movements" (p. 6). These are strategies that could support the implementation of both Principles 5 and 6.

The literature highlights the crucial role of assessments in advancing equity-centered engineering education. By evaluating students' sociotechnical thinking, these assessments ensure that future engineers are equipped to consider both societal and ethical/contextual dimensions in their work. Implementing inclusive and equity-oriented assessments supports modern engineering education's goals and fosters a professional identity grounded in social responsibility. As Nieminen [115] suggests, continually evolving these tools is essential for advancing equity within engineering education and preparing students to address complex, real-world challenges.

Examples of Principle 6 in practice are limited

However, it is evident that there is limited literature on how to assess students' learning of equity-centered and sociotechnical engineering. When we asked interview participants how they approached this task, they often shared that they had not implemented assessment of equity-centered course content to the extent they would like. However, a few instructors shared strategies they had used, including requiring students to show "evidence that they've accounted for some user with needs different from their own"; providing formative feedback encouraging students' further reflection on the implications section of their software product documentation; and building a requirement into the rubric of a design project for students to discuss the social considerations of their designs for which they either had or had not accounted. It is notable that all of these strategies are highly rooted in the design context. As highlighted in the previously discussed literature, it can be difficult to integrate equity content into the majority of core engineering courses, which are primarily technical ([18], [12]), and is thus similarly more difficult to assess student learning of this content outside of the design context. Rodrigues and Seniuk Cicek [36] found in their scoping literature review of sociotechnical thinking in engineering education that "the least common research purpose …was the development of instruments to measure [sociotechnical thinking]" (p. 11). In short, this principle is important and supports other principles, sending the message to students that sociotechnical and equity-centered engineering content is relevant, though this principle is also difficult, and as of yet, there are limited examples of assessment strategies for instructors to adapt.

Conclusion

In this paper, we have presented six principles that are a component of a developing framework for equity-centered engineering curriculum and instruction. Although we present them individually, our discussion throughout demonstrates how the principles are interconnected conceptually and practically, revealing how content and instruction are intertwined and mutually supporting. Additionally, while we make no claims that any principle is more or less important than any other, we recognize that instructors may approach the work of implementing these principles in steps. Ideally, instructors and instructional developers using our framework would keep all the principles in mind, but use the framework flexibly to implement the principles they think are most appropriate and applicable first, and then add more over time.

Ultimately, we aim to provide a dynamic framework, including the foundational concepts mentioned in the Introduction, in addition to the six principles presented here. The framework will highlight diverse examples from literature and our interviews across a range of courses, and present reflective questions to aid instructors in implementing these strategies, by adapting existing material or developing new equity-centered engineering courses and content. We also intend to study our framework in practice and refine it as needed to ensure it can be used in a variety of institutional contexts.

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