Assessing Sociotechnical and Justice Learning in a Community Partnership-Based Biomedical Engineering Capstone Course

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Abstract

Undergraduate engineering students are increasingly engaged in community-partnered and global health design, yet there remain limited approaches for exploring how capstone courses support learning related to sociotechnical reasoning (the connection between humans and technology), justice (giving others what they are owed), and ethical responsibility (doing what is right). This exploratory study examines learning outcomes in a senior biomedical engineering capstone course that integrates human-centered design, project-based learning, and anti-oppressive pedagogy through sustained community partnerships. Building on prior work that established the course's pedagogical framework, the present study shifts focus to assessment. Using a mixed-methods approach, we analyze matched pre/post survey responses and structured student reflections to explore changes in how students frame design problems, integrate social considerations, and reason about power and responsibility over the semester. Findings suggest developmental movement in sociotechnical and justice-oriented reasoning, while values-based orientations remain relatively stable. Qualitative analysis provides additional insight into how technical and ethical reasoning co-develop in practice. This work demonstrates the feasibility of exploring justice-oriented learning in capstone design and informs future assessment and course development efforts.

1. Introduction

Over the past two decades, global health has expanded as a field within U.S. higher education, reflected in the growth of academic programs and funding initiatives [1], [2], [3]. Biomedical engineers have long engaged in global and community health efforts through device innovation, humanitarian design initiatives, and projects aligned with the Sustainable Development Goals [4], [5], [6]. At the same time, researchers and practitioners have increasingly called for the decolonization of global health, highlighting how traditional research and innovation models have often operated through uneven power dynamics, extractive partnerships, and insufficient attention to structural inequities [7], [8], [9], [10]. The COVID-19 pandemic further exposed systemic disparities in health systems and biomedical innovation, intensifying scrutiny of how health technologies are developed, distributed, and governed [11], [12]. Within this evolving landscape, engineering education must prepare students not only to design technically effective solutions, but also to critically engage with the sociotechnical systems and power structures in which those technologies operate [13].

Many undergraduate students enter biomedical engineering (BME) with an interest in solving complex, socially relevant problems, yet often lack structured preparation for the ethical, contextual, and practical challenges inherent in global health and community-engaged design [12], [13], [14], [15]. Biomedical technologies are developed and deployed within systems shaped by historical inequities, power relations, and uneven access to care, making it essential that engineering students are prepared to engage with these dimensions as part of their design practice.

This gap between technical preparation and contextual readiness has fueled growing interest in educational approaches that center community accountability, equity, and ethical responsibility alongside design skills [16], [17], [18].

This senior BME capstone course is grounded in the integrated use of human-centered design (HCD) [19], [20], project-based learning (PjBL) [21], and anti-oppressive pedagogy (AOP) [22], [23] to support community-engaged, justice-oriented design work. HCD and PjBL together provide a foundation for engaging students in authentic, ill-structured design challenges with real partners. HCD emphasizes empathetic engagement in the design process through understanding the needs and experiences of the end-user [24], while a PjBL lens applied to the same projects encourages teamwork, communication skills, and collaborative problem-solving [21], [25].

Despite these documented benefits, scholars have raised concerns that HCD and PjBL may insufficiently address systemic inequities when social considerations are treated as secondary constraints rather than integral components of engineering judgment [26]. Without explicit instructional scaffolding, students may focus on individual user needs while overlooking broader sociopolitical, historical, and economic forces that shape health outcomes and technological implementation [27], [28]**.** This limitation is particularly salient in global health and community-partnered projects, where power asymmetries between engineers and communities can be inadvertently reproduced through well-intentioned but insufficiently critical design practices [29].

Anti-oppressive pedagogy (AOP) offers a complementary framework for addressing these limitations by explicitly foregrounding power, positionality, and systemic inequity within educational contexts [23]. Rooted in critical pedagogy—an approach that encourages learners to question dominant narratives, examine how knowledge is constructed, and analyze structures of power—AOP encourages learners to interrogate whose knowledge is valued, how professional practices can perpetuate harm, and what ethical responsibilities engineers hold when working with marginalized communities [30]. Within engineering education, emerging work has argued that justice-oriented and equity-centered pedagogies are necessary to support students' development of sociotechnical reasoning, humility, and ethical agency [15], [16], [31]. Here, sociotechnical reasoning refers to the capacity to understand technical design decisions as inseparable from their social, cultural, political, and economic contexts, and to evaluate engineering work in light of those interdependencies. Rather than replacing HCD, AOP can be integrated alongside design frameworks to support a shift from "designing for" communities toward more collaborative "designing with" approaches.

Accordingly, we designed a senior BME capstone course that integrates HCD, PjBL, and AOP to support community-engaged, justice-oriented design work. The course emphasizes collaboration with both global and local community partners and incorporates modules that foreground historical and social contexts of global health, reflection on positionality and privilege, and the need to prioritize equity and sustainability alongside technical performance. Through co-learning and co-development with community partners, students are encouraged to recognize that systemic inequities shape both global and local engineering challenges and to approach design as a sociotechnical practice. This approach aims to shift students' perspectives from a narrow technical focus toward a more holistic view of engineering that accounts for historical context, social impact, and systemic inequality throughout all phases of the design process.

In prior work, we reported on the initial implementation of this course and the integration of AOP-informed modules within a senior BME capstone (19 of 24 consented) [32]. Qualitative analysis of post-course student reflections suggested shifts in how students articulated their engineering identities, ethical responsibilities, and relationships with community partners. However, that pilot relied primarily on qualitative evidence, with limited use of post-course quantitative data, thereby limiting insight into how these learning outcomes developed over time.

The present study builds on the same capstone course by shifting focus from pedagogical design to assessment. Using a mixed-methods strategy that combines matched pre/post instruments with structured reflection, this study examines whether the integrated use of HCD, PjBL, and AOP supports students' development of sociotechnical reasoning, justice-oriented perspectives, and reflective engagement with community partners over the course of the semester. We hypothesize that participation in the course is associated with measurable changes in how students reason about engineering design problems, including increased attention to structural context, power, and responsibility, alongside continued development of technical design skills.

2. Literature Review

The theoretical foundations of this course integrate human-centered design (HCD), project-based learning (PjBL), and anti-oppressive pedagogy (AOP) to support community-engaged, justice-oriented biomedical engineering design. AOP provides a critical complement by foregrounding issues of power, positionality, and systemic oppression, encouraging students to examine how engineering practices can reproduce or disrupt inequity. These integrated theoretical foundations and their pedagogical implementation are described in detail in prior work projects [32]. The present study builds on that foundation by focusing on improved methods for assessing the learning outcomes associated with these theories, and on examining themes that emerged during the pilot implementation.

2.1. Assessment Tools for Global, Sociotechnical, and Justice-Oriented Learning

Though a wide range of tools are used to assess learning related to global engagement, sociotechnical reasoning, and ethics, few are specifically developed and validated for engineering applications. In global and community-based learning contexts, commonly used instruments include measures of intercultural competence and global engagement, such as the Global Engagement Survey (GES), which has demonstrated reliability and construct validity across diverse institutional [33], [34]. The GES is designed to characterize students' orientations along multiple broad dimensions of global learning, rather than discipline-specific professional competencies. For example, one item asks students what extent they agree with the statement "I carefully consider how dominant cultural assumptions reinforce inequalities."

Within engineering education, additional instruments have been developed to assess global or sociotechnical competencies more narrowly tied to engineering practice. In particular, the Global Engineering Competency Scale (GECS) was developed to assess engineers' readiness to function effectively in international and cross-cultural professional engineering contexts [35]. While this is well-suited for career preparation and professional practice, the scale's items less directly align with the learning outcomes of our community-based course focused on ethical inquiry, partnership, and structural critique. In other words, this scale does not explicitly assess students' ability to examine how larger systems such as historical inequities, institutional structures, and power hierarchies shape global health work and influence whose knowledge and priorities are centered. As a result, many community-engaged engineering courses continue to rely on reflective writing, project artifacts, or locally developed surveys to assess ethics integration, approaches that are often implemented without extensive metric validation or multi-institutional testing [36].

Recent work has begun to address this gap through the development of justice- and sociotechnical-focused instruments that explicitly foreground equity, systems, and context in engineering practice. The Engineering Social Justice Scale (ESJS) was developed to assess students' orientations toward social responsibility and structural injustice in engineering, with published studies reporting exploratory factor analysis and reliability evidence [31]. Similarly, the Global Sociotechnical Competency Scale (GSCS) was developed to assess students' ability to integrate technical and social considerations in engineering problem-solving, particularly in humanitarian and global health contexts, with items such as "I feel confident integrating perspectives from non-engineers into my engineering design projects" [37]. However, the metrics in this scale have not yet been validated through exploratory or confirmatory factor analysis. While confirmatory validation for these instruments is still emerging, together they reflect an effort to move beyond attitude-based measures toward assessment of systemic and structural dimensions of engineering learning.

In the present study, items from the Global Engagement Survey (GES) are used as a validated tool for level-setting and for capturing students' broad engagement with the course and can be used to assess project-based learning outcomes around teamwork and listening. Items from the Engineering Social Justice Scale (ESJS) are used and grouped according to their exploratory factor structure, a statistical method that examines how survey items cluster together to reflect underlying constructs. From this structure, we selected items most relevant to AOP. Items from the Global Sociotechnical Competency Scale (GSCS) are employed to support interpretation of students' engagement with the technical and social dimensions of design, specifically how students reason about human-centered design compared to traditional engineering design alone. Together, these assessment tools are used to maintain consistency in reporting across scales, including those in preliminary stages of development, in combination with reflective data.

2.2. Developmental and Sensemaking Perspectives on Ethical and Sociotechnical Reasoning

A growing body of engineering education research emphasizes that ethical, sociotechnical, and justice-oriented reasoning develops over time through repeated engagement with ill-structured problems rather than being acquired as a fixed set of skills [38]. Sensemaking perspectives conceptualize ethical reasoning as an interpretive process in which individuals navigate ambiguity, integrate competing values, and construct meaning in context, particularly when technical decisions have social and ethical consequences [28]. In this course, for example, students must grapple with competing priorities within their projects. Teams may need to weigh cost against expanded functionality, technical rigor against realistic training and use expectations in a busy healthcare setting, or their own engineering judgment against feedback from clinicians, community leaders, or patients. From this view, ethical competence is not defined by adherence to prescriptive rules, but by the capacity to recognize ethically salient features of situations and reason through them reflectively.

Developmental theories of reflective judgment further support this framing by describing how individuals' epistemic assumptions evolve as they encounter problems without clear right answers. King and Kitchener's model characterizes progression from reliance on authority and certainty toward more contextualized, evidence-based, and reflective forms of reasoning [39]. These developmental shifts are especially relevant in engineering design education, where students must routinely negotiate uncertainty, tradeoffs, and power dynamics [29].

Within capstone and community-engaged design contexts, these frameworks suggest that learning outcomes should be understood as changes in how students frame problems, justify decisions, and articulate responsibility, rather than as discrete competencies achieved by the end of a course [40]. As a result, assessment approaches that combine pre/post measures with qualitative reflection are particularly well-suited to capturing developmental changes in ethical and sociotechnical reasoning.

2.3. Anti-Oppressive Approaches to Power, Ethics, and Design in Engineering

Anti-oppressive pedagogy (AOP) extends developmental and sensemaking frameworks by explicitly foregrounding power, positionality, and structural inequities as central components of ethical engineering practice [41]. While project-based learning (PjBL) and community-engaged design offer meaningful experiential learning opportunities, scholarship in service-learning and community partnership has cautioned that without explicit attention to power, privilege, and reciprocity, poorly structured or short-term engagements can strain community organizations and reproduce inequitable dynamics [29], [42]. Because of this, traditional service-learning models may center student learning outcomes over community-defined priorities, particularly when projects are semester-bounded or lack mechanisms for sustained accountability or feedback from the community [43].

These concerns, alongside emerging research on the impact of such partnerships on community partners themselves [44], informed the development of a continuum of decolonizing engineering design, described in prior work [32]. This continuum outlines a progression from more university-centered models toward approaches that emphasize greater community participation and equity in partnership structures. Within that framework, AOP was integrated to more explicitly foreground accountability, reciprocity, and attention to power within community-based design work. This positions HCD and PjBL to support longer-term, more equitable collaboration rather than short-term, project-bound engagement. It also shifts responsibility to the instructional team to maintain continuity and accountability in community partnerships from one semester to the next.

From an AOP perspective, ethical design projects involve students developing the capacity to critically examine whose knowledge is valued, how partnerships are structured, and how design decisions may reproduce or disrupt existing power relations. Rather than focusing solely on individual attitudes or behaviors, AOP emphasizes how historical, political, and economic systems shape engineering problem definition, design processes, and technological outcomes [45], [46], [47], [48]. In engineering education, this perspective challenges dominant framings of engineering as value-neutral and calls for instructional approaches that make structural dimensions of harm and inequity visible. For example, in this class, rather than treating engineering problems as objective or purely technical, students are asked to consider why the problems they are addressing remain unresolved, how historical and geopolitical forces have contributed to their persistence, and how existing systems of funding, governance, and infrastructure shape what solutions are possible or prioritized.

Critical scholarship in engineering education has similarly highlighted how traditional ethics instruction often focuses on individual responsibility while overlooking larger systemic forces such as colonial histories, institutional power, and unequal distributions of risk and benefit—dynamics that are especially important in global health and community-based design contexts [48]. In these settings, engineers often work with communities that have been historically marginalized by technological and medical systems. For example, projects in this course often focus on technologies aimed at improving women's health, gender-minority and racial minority health, or addressing strained patient-to-provider ratios. These challenges are especially evident in under-resourced and rural settings, both within the United States and globally.

Collectively, developmental, sensemaking, and anti-oppressive perspectives frame ethical and sociotechnical learning as evolving processes shaped by context, power, and relationships, underscoring the need for pedagogical and assessment approaches that account for how students reason about systems and responsibility.

3. Course Design

As is reported previously, the course is offered as a senior capstone design laboratory and is organized around team-based projects sourced through community partnerships [32]. As described in that prior work, the course is structured around the three phases of a human-centered design cycle: Hear, Create, and Deliver. In the Hear phase, students engage stakeholders and examine community context through interviews, background research, and needs identification. The Create phase centers on iterative prototyping, trade studies, and refinement grounded in partner feedback. The Deliver phase focuses on testing, validation, documentation, and sustainability planning to support long-term community use. These phases provide a conceptual structure for the semester and guide the sequencing of assignments, partner engagement, and reflection. While the theoretical framing of the course remains consistent with the prior year's implementation, the Fall 2025 offering included several logistical and instructional refinements intended to better align course structure, student work, and assessment.

The instructional team identified and secured community partner organizations and design projects that were both feasible for a one-semester capstone and technically meaningful. Students were also invited to propose projects sourced independently over the summer. These included devices to support newborn breathing in understaffed maternity wards, systems to monitor individual heat exposure and its acute health effects among farmworkers, and educational platforms to supplement microsurgery training in clinics with limited specialist capacity. Across all offerings, projects were sourced both from the local Durham, North Carolina community and international locations such as Kampala, Uganda and Cajamarca, Peru. Projects spanned both global and local contexts to allow students to engage with distinct sociopolitical and healthcare environments while applying the same design framework.

Logistically, each week consisted of two 75-minute classroom meetings (Tuesdays and Thursdays) and a three-hour laboratory session (Mondays). Monday lab sessions began with focused skill-building activities to establish prototyping competencies, then transitioned early in the semester to primarily support team-based project work, with structured weekly check-ins to monitor design progress and provide formative feedback. Classroom sessions were designed to support conceptual, contextual, and reflective learning. Tuesday meetings generally focused on content delivery and active learning through short lectures, discussion-based activities, and case study analysis. Thursday meetings were largely repurposed as structured project work periods for teams to meet to advance design tasks, integrate partner feedback, and plan next steps, with the instructional team facilitating discussions and providing targeted guidance. This restructuring was intended to provide protected time for applying course content directly to project decisions and to better reflect the iterative nature of design work.

Instructional content and readings were reorganized in Fall 2025 to more intentionally align with students' progression through the design process and to reduce the reading load for students (Table 1). This change responded to student feedback that the reading load was substantial and occasionally redundant. The revised structure reduces volume to support deeper engagement and to create additional time for applying concepts directly to project decisions. Readings were grouped into thematic clusters that mapped directly onto weekly design activities and milestones, encouraging students to apply key concepts from the readings directly to their ongoing project work. To support peer learning and discussion, the course incorporated a social annotation tool (Hypothesis), which allowed students to share insights, questions, and responses directly within the readings. This approach helped students arrive in class prepared for discussion and shifted classroom time toward collective sensemaking and application rather than content delivery.

Table 1. Progression of thematic content of readings as linked to progressive elements of the design process.

Lecture	Content Theme	Design Theme
1	Intro and human-centered design foundations	Project overviews and conducting interviews
2	Local context and oppression in global health	Needs statement, and design criteria
3	Decolonization and anti-oppressive partnerships	Prior art search, brainstorming, trade studies
4	Lack of equity in global health research and practice	Critical evaluation of evidence and sources, technical writing
5	Medical device regulation and design ecosystem in the US	Testing (verification and validation)
6	Medical device regulation and design ecosystems in LMICs	Testing (verification and validation)
7	Design for sustainability	Project sustainability through documentation
8	Global health x engineering in educational partnerships	Partner engagement, communication, and collaboration
9	Addressing power asymmetries and movement building	Long-term impact planning and systems-level engagement

Early lecture themes introduced human-centered design foundations and oriented students to their selected projects, with emphasis on project scoping and conducting interviews with community partners. This was followed by a focus on local context and structural oppression in global health, supporting students as they developed needs statements and design criteria grounded in community-defined priorities. As projects moved into ideation, instruction shifted toward decolonization and anti-oppressive partnership practices, providing a framework for evaluating prior art, brainstorming solutions, and conducting trade studies with explicit attention to power and equity. This process allowed for topics of power and equity to be embedded in technically rigorous engineering methods to legitimize these themes as valuable parts of the design process.

Mid-semester lecture content and readings addressed inequities in global health research and practice, prompting students to critically examine how knowledge is produced, represented, and applied in design contexts. Discussions highlighted differences between oral and written knowledge traditions, the high cost of academic publishing, and the influence of English as the dominant language of scholarship. Through conversations about evaluating evidence, technical writing, and the open-access movement, students examined how these systems shape whose knowledge is recognized and how that recognition affects engineering design decisions.

Instruction then transitioned to medical device regulation and design ecosystems, first within the United States and subsequently in low- and middle-income country contexts, aligning with students' work on verification, validation, and testing. Later instructional themes emphasized sustainability and documentation to support long-term project viability and handoff planning. The course concluded with content focused on global health and engineering partnerships and on addressing power asymmetries through collective action and movement building, situating student projects within broader systems and ongoing efforts toward health equity.

Assignments were scaffolded to mirror the phases of the HCD-informed design process, from community context research and needs identification through prototyping, testing, and handoff planning. Teams maintained a continuously updated design file composed of sequential written assignments, each revised iteratively as projects evolved. Peer evaluation was embedded within team assignments to promote accountability and reflection on collaboration.

Each team worked with their designated community partner, and partner input was incorporated throughout the design process through interviews, feedback sessions, and review of design decisions. Oral presentations aligned with the "Hear," "Create," and "Deliver" phases of the design process were shared with partners to solicit feedback and reinforce reciprocal engagement. Individual reflections at the beginning and end of the semester supported students' examination of their learning, positionality, and design decision-making.

Figure 1 provides an overview of the course structure and illustrates how weekly logistics, instructional themes, and assignments align with the HCD-informed design process, with AOP-informed modules integrated across the Hear, Create, and Deliver phases.

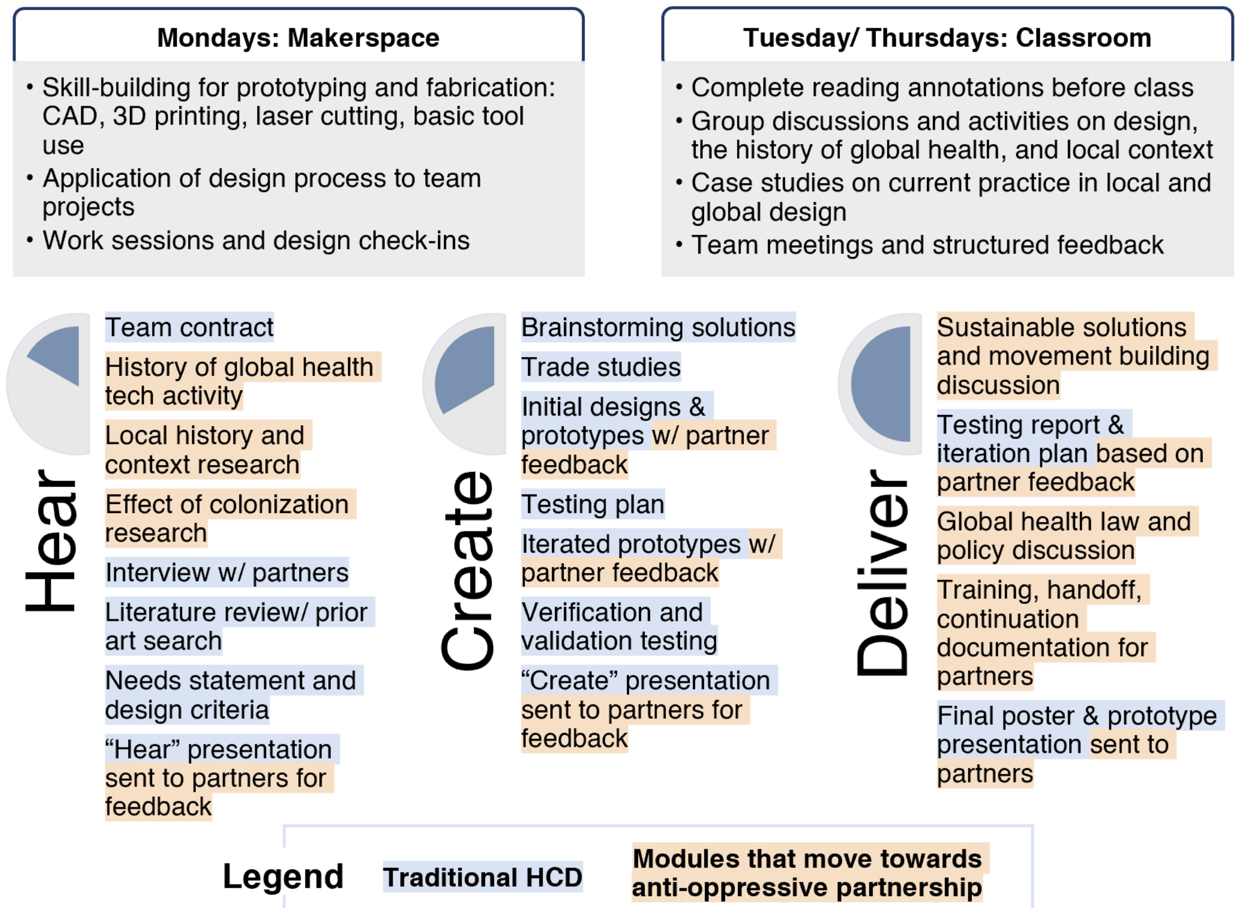

Figure 1. Course structure and implementation overview.

4. Methodology

Data were collected across multiple course offerings (Total [n=29]: Fall [n = 19], Spring 2025 [n = 3], and Fall 2025 [n=7]), with the most recent Fall 2025 cohort participating in an expanded mixed-methods assessment. Although all 38 students who took this course from Fall 2024-Fall 2025 completed these assignments as part of their class, 29 consented to participate in the research component. Participation in research was voluntary and approved by the Duke University Campus

Institutional Review Board (protocol number 2025-0212). All data were anonymized prior to analysis.

A subset of items from the Global Engagement Survey [49] was administered post-course in Fall 2024 and Spring 2025 to assess student orientations related to openness to diversity, cultural adaptability, and critical reflection—components selected for their relevance to community-centered design and ethical reflection in global health education. Descriptive statistics from AY 2024–25 indicated consistently high post-course scores across components, consistent with prior applications of the GES in upper-division, self-selected courses and suggesting limited sensitivity for detecting nuanced developmental change within a single course. To examine whether this pattern persisted across semesters, responses were aggregated for items conserved across administrations, and mean Likert scores with confidence intervals were calculated by cohort (Figure 2).

These pilot data relied on post-course reflections and course evaluations only, limiting the ability to examine student growth over the semester. To address this limitation, the Fall 2025 iteration implemented matched pre- and post-course surveys alongside revised initial and final written reflections, enabling descriptive comparisons over time. Given the course's explicit emphasis on justice-centered design and sociotechnical reasoning, additional validated instruments were introduced in Fall 2025 to directly assess these dimensions, informed by themes identified in qualitative analysis of prior student reflections.

All seven students in the Fall 2025 section completed revised initial and final reflections with short-answer questions and validated Likert-scale instruments measuring cultural humility, agency in community-engaged engineering, and justice orientation. These Likert instruments included components from the Global Engagement Survey (GES) [49], the Global Sociotechnical Competency Scale [37], and the Engineering Social Justice Scale (ESJS) [31]. While the course is structured as project-based learning, we did not employ a standalone validated PjBL instrument; rather, survey items were selected to examine how AOP and HCD principles were enacted within a project-based context. A mean score and 95% confidence interval for each component was aggregated from its component items, and the pre- to post-semester differences were calculated. Given the small sample size, pre/post semester comparison analysis was limited to descriptive statistics, and results are interpreted as exploratory rather than inferential. All Likert scale instruments used are in Appendix A.

Initial reflection short-answer questions prompted students to articulate prior experiences, motivations, and perspectives related to engineering, design, ethics, and community engagement. Final reflections invited students to revisit these topics after the course, with additional prompts encouraging reflection on learning, assumptions, and future professional practice (full reflection prompts can be found in Appendix B). Reflection data were analyzed using a hybrid inductive qualitative coding approach. Initial codes were developed inductively based on (1) the reflection prompts used in the course and (2) themes that emerged from a pilot analysis of student reflections from a prior course offering projects [32]. Inductively generated codes were grouped into six broader thematic domains that captured recurring areas of student reasoning observed across reflections. These domains were: (1) community and partnership orientation; (2) critical reflection and metacognition; (3) design process understanding; (4) engineering identity and role perception; (5) humility and limits of expertise; and (6) justice, power, and inequity.

Within each domain, codes were organized into four ordered qualitative levels, forming thematic continua intended to represent qualitatively distinct ways students framed and reasoned about the same topic. Lower levels reflect more immediate, descriptive, or technically focused framings, while higher levels reflect broader consideration of context, responsibility, and ethical implications. Organizing themes in this way follows established qualitative approaches that treat reflection, ethical reasoning, and professional identity as varying in complexity and depth, rather than as binary traits [15], [29], [39], [50], [51]. Reflections were coded at the level of meaningful text segments. A single segment could be coded under multiple themes if it addressed more than one area of reasoning, but within each theme it was assigned to only one level. Coded segments were aggregated by theme, level, and reflection phase (initial versus final). Coded segment counts were used to support visual comparison of reasoning patterns across themes and reflection phases, not to make claims about statistical significance or individual student trajectories. The codebook and description of each level can be found in Appendix C. Because students were not consented to research participation until near the end of the semester, initial and final reflections were analyzed together after the course concluded. The codebook was developed inductively using the full set of de-identified reflections (both initial and final) and then applied consistently across both phases. The same codebook and decision rules were used to support comparison over time.

Qualitative and quantitative findings were interpreted in tandem to examine patterns in students' sociotechnical and justice-oriented learning across the semester.

5. Results and Discussion

5.1. Cross-Year Post Survey Comparisons

Post-course survey data collected during AY 2024–25 were obtained as part of a pilot implementation that focused primarily on qualitative analysis of student reflections. In that academic year, initial and final reflections served as the main data source for examining student learning and formed the basis of the qualitative findings reported in the prior ASEE paper [32]. Those analyses documented shifts in students' conceptions of engineering identity, community partnership, and ethical responsibility, as well as variability in the depth of students' engagement with issues of power, humility, and justice.

In AY 2024-2025, Global Engagement Survey (GES) components were added at the end of the semester to provide supplementary quantitative context for these qualitative findings, rather than to function as primary outcome measures or to capture within-semester change. As such, the post-only survey data from AY 2024–25 are interpreted as context-setting, intended to assess whether themes emerging from the qualitative analysis were broadly reflected in students' self-reported attitudes at the conclusion of the course. As shown in Figure 2, post-course scores of the AY 2024-25 cohort and the Fall 2025 class followed a similar overall pattern (Table 2). Openness to Diversity, reflecting receptivity to cultural difference, and Critical Reflection, capturing students' examination of privilege and dominant assumptions, did not differ significantly between the two cohorts. Cultural Adaptability, which measures behavioral flexibility and communication adjustment across contexts, was higher in Fall 2025 and reached statistical significance. Notably, Fall 2025 was the first cohort for which matching pre-course measures were collected, and students entered the semester with a relatively high baseline Cultural Adaptability score ($\bar{x}$ = 4.24, SD = 0.58). This suggests that the cross-year difference may reflect cohort-level variation in prior global or intercultural experiences rather than course-related effects alone.

Table 2: Means, standard deviations, test statistics, degrees of freedom, and exact *p*-values for all constructs.

Construct	**AY 2024–25 (Mean ± SD)**	**Fall 2025 (Mean ± SD)**	**t(df) = Test Statistic**	**p-value**
Openness to Diversity	4.37 ± 0.48	4.62 ± 0.59	t(8.78) = 0.99	0.347
Critical Reflection	4.18 ± 0.72	4.09 ± 0.54	t(13.61) = −0.32	0.755
Cultural Adaptability	3.93 ± 0.73	4.57 ± 0.51	t(14.55) = 2.55	0.022

These results suggest that post-course survey responses were broadly comparable across offerings and that the qualitative patterns identified in the pilot study are unlikely to be artifacts of a single semester. These results are presented descriptively to illustrate overall response patterns and inform subsequent assessment decisions.

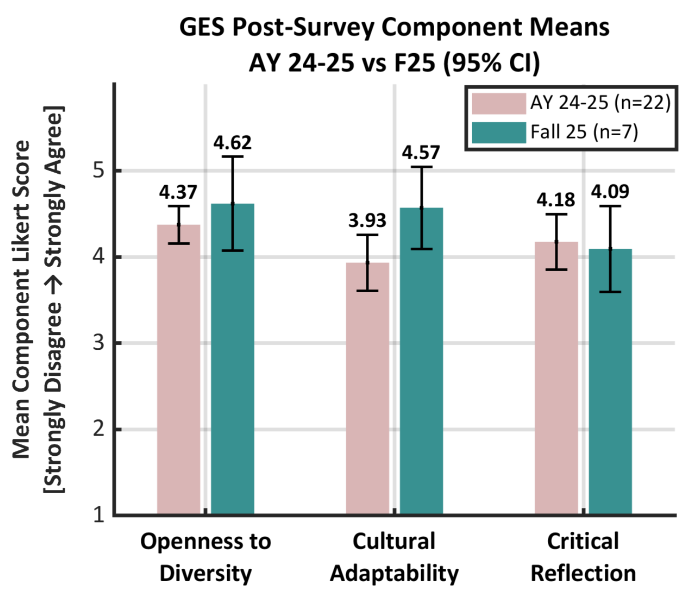

Figure 2. Cross-year comparison of conserved Global Engagement Survey (GES) component means. Post-course mean Likert-item scores (± 95% confidence intervals) for conserved Global Engagement Survey (GES) components across three academic semesters: AY 2024–25 (n = 22) and Fall 2025 (n = 7). AY 2024–25 (n = 22) combines Fall 2024 and Spring 2025. Across both years, students reported the highest scores in Openness to Diversity.

5.2. Pre-Post Semester Quantitative Analysis

To better understand how these survey themes specifically connect to students' engineering identities, seven students in the Fall 2025 semester completed updated pre- and post- surveys reflecting nine total components across 25 Likert-scale items. Most sociotechnical, identity, and justice-oriented components exhibited positive pre–post mean differences (Figure 3), though these results should be interpreted as descriptive and exploratory rather than inferential, given the small sample size and overlapping confidence intervals.

Component	Pre (Mean ± 95% CI)	Post (Mean ± 95% CI)
Openness to Diversity	4.67 ± 0.25	4.62 ± 0.45
Cultural Adaptability	4.24 ± 0.43	4.33 ± 0.53
Critical Reflection	3.62 ± 0.57	4.10 ± 0.34
Integrating Social Concerns	4.52 ± 0.43	4.76 ± 0.34
Self Efficacy	3.86 ± 0.99	4.14 ± 0.64
View of Engineering	4.71 ± 0.36	4.50 ± 0.38
Justice Attitudes and Intent	4.79 ± 0.26	4.74 ± 0.32
Justice Norms	3.90 ± 0.58	4.14 ± 0.43
Community Efficacy	4.57 ± 0.73	4.71 ± 0.70

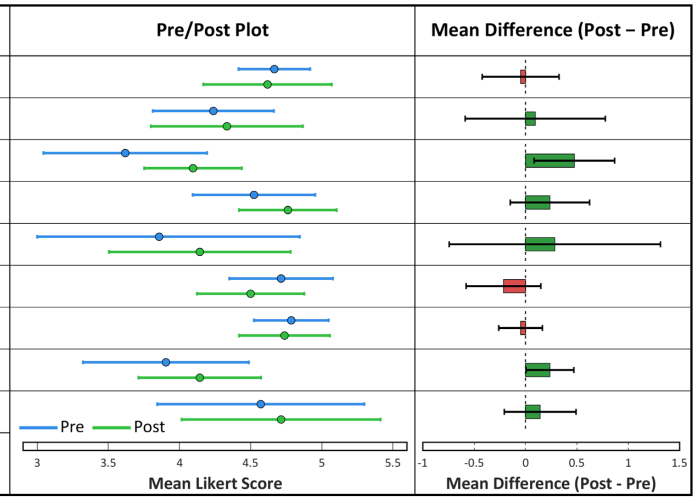

Figure 3. Pre–post survey means and mean differences for sociotechnical and justice-related constructs. Pre- and post-semester mean Likert scores (± 95% confidence intervals) and corresponding mean differences (post − pre) for sociotechnical, identity, and justice-oriented survey constructs from the Fall 2025 cohort. The center panel displays pre- (top) and post-course means (bottom), while the right panel shows mean differences across the semester. Positive values indicate increases over the semester.

The Openness to Diversity component consisted of items assessing general receptivity to cultural differences (e.g., openness to different lifestyles, enjoyment of learning from culturally different peers). This component exhibited a high post-course mean ($\bar{x}$ = 4.62) with negligible pre–post change ($\Delta = -0.05$). This pattern mirrors prior Global Engagement Survey (GES) findings, which consistently report high baseline scores and limited detectable change for openness-related items due to ceiling effects in globally oriented courses. The Cultural Adaptability component, which captures students' perceptions of their ability to adjust their behavior and communication in different cultural settings, showed a small positive change ($\Delta = +0.10$). GES analyses indicate that adaptability items are modestly sensitive to experiential learning, and the observed pattern is consistent with increased attention to context and communication reflected in student reflections.

Notably, Critical Reflection exhibited the lowest post-course mean among all components ($\bar{x}$ = 4.10) but the largest positive pre–post change ($\Delta = +0.48$). The items comprising this component explicitly prompt interrogation of power, privilege, and the contingency of knowledge (e.g., recognizing how dominant assumptions reinforce inequality and that one's "truths" are open to change). Prior GES research identifies critical reflection as both more challenging for students and more sensitive to pedagogical scaffolding than openness- or attitude-based components [34], [49]. The observed pattern therefore suggests developmental movement toward more reflexive ways of knowing rather than acquisition of new values, a finding reinforced by qualitative shifts toward critical self-interrogation in post-semester reflections.

From the Global Sociotechnical Competency Scale [37], the Integrating Social Concerns component (items 10–12) measured confidence in incorporating stakeholder and non-engineer perspectives into design, and showed a positive mean difference ($\Delta = +0.24$). This aligns with sociotechnical competency literature indicating that confidence in sociotechnical integration develops through practice rather than value endorsement. Self-Efficacy (item 13), which refers to students' belief in their own ability to succeed in engineering tasks and perform effectively as engineers, also increased ($\Delta = +0.29$), though with greater variability. Prior research suggests that engineering self-efficacy often develops unevenly in justice-oriented contexts, as students reconcile technical competence with expanded ethical responsibility. In contrast, the View of Engineering component (items 14–15), which assessed fulfillment in engineering and perceived ability to effect change through engineering, showed a slight negative mean difference ($\Delta = -0.21$) despite a high post-course mean ($\bar{x} = 4.50$). This pattern aligns with prior sociotechnical and humanitarian engineering research, which documents moments of productive disillusionment, where students develop more realistic, less idealized views of engineering's limits even as their commitment to ethical practice deepens [29], [31].

From the Engineering Social Justice Scale (ESJS) [31], the Justice Attitudes and Intent component (items 16–18, 23–25) exhibited minimal change ($\Delta = -0.05$) alongside a very high post-course mean ($\bar{x} = 4.74$). This mirrors findings from ESJS, where justice-oriented beliefs are often strongly endorsed early and show limited short-term movement. By contrast, the Justice Norms component (items 19, 21, 22), which assessed perceptions of peer engagement and awareness of social injustice, showed positive change ($\Delta = +0.24$). ESJS research indicates that subjective norms are more responsive to instructional context than personal attitudes, reflecting shifts in how students perceive disciplinary culture. Finally, Community Efficacy (item 20) showed a modest increase ($\Delta = +0.14$), suggesting emerging confidence in students' ability to enact sociotechnical change in their own communities through engineering.

This exploratory analysis provides a foundation for ongoing longitudinal data collection in future course offerings. In addition to assessing sociotechnical and justice-oriented learning outcomes, the results contribute to a broader University initiative focused on integrating virtue ethics and character strengths into engineering education. Virtue ethics is a moral framework that emphasizes the development of enduring character traits, such as humility, justice, courage, and practical wisdom, rather than focusing only on rules or outcomes. In this view, ethical practice emerges from cultivating habits of reflection and judgment that shape how individuals act across contexts. The findings help identify character strengths most closely aligned with this capstone experience, which will inform subsequent course development and targeted instructional interventions as part of this initiative. Metrics not reported in the present study serve as baseline measures and will be examined and reported alongside other course outcomes as additional cohorts complete the course, allowing for continued assessment of the stability of all trends.

5.3. Pre-Post Semester Qualitative Analysis

Student reflections were inductively coded across six themes: Community and Partnership Orientation, Critical Reflection and Metacognition, Design Process Understanding, Engineering Identity and Role Perception, Humility and Limits of Expertise, and Justice, Power, and Inequity. Each was organized as an ordered continuum of qualitatively distinct levels of thought about the same topics (Figure 4).

Community and Partnership Orientation captured how students positioned communities in the design process, ranging from viewing them as passive recipients to co-creators and partners with shared authority and long-term accountability. Critical Reflection and Metacognition described the depth of students' reflection, from descriptive accounts of experiences to critical self-interrogation and shifts in worldview or professional identity. Design Process Understanding reflected how students conceptualized engineering design, from linear and solution-first approaches to iterative, human-centered, and explicitly anti-oppressive or decolonial frameworks. Engineering Identity and Role Perception examined how students understood the role of the engineer, progressing from a primarily technical problem-solver to an ethical and sociotechnical actor embedded within broader systems. Humility and Limits of Expertise assessed students' recognition of uncertainty and the legitimacy of non-engineering knowledge, culminating in reflexive humility and self-critique. Justice, Power, and Inequity captured the extent to which students recognized disparities, analyzed structural forces shaping inequity, considered engineering's role in reinforcing or disrupting those systems, and articulated commitments to justice-oriented action.

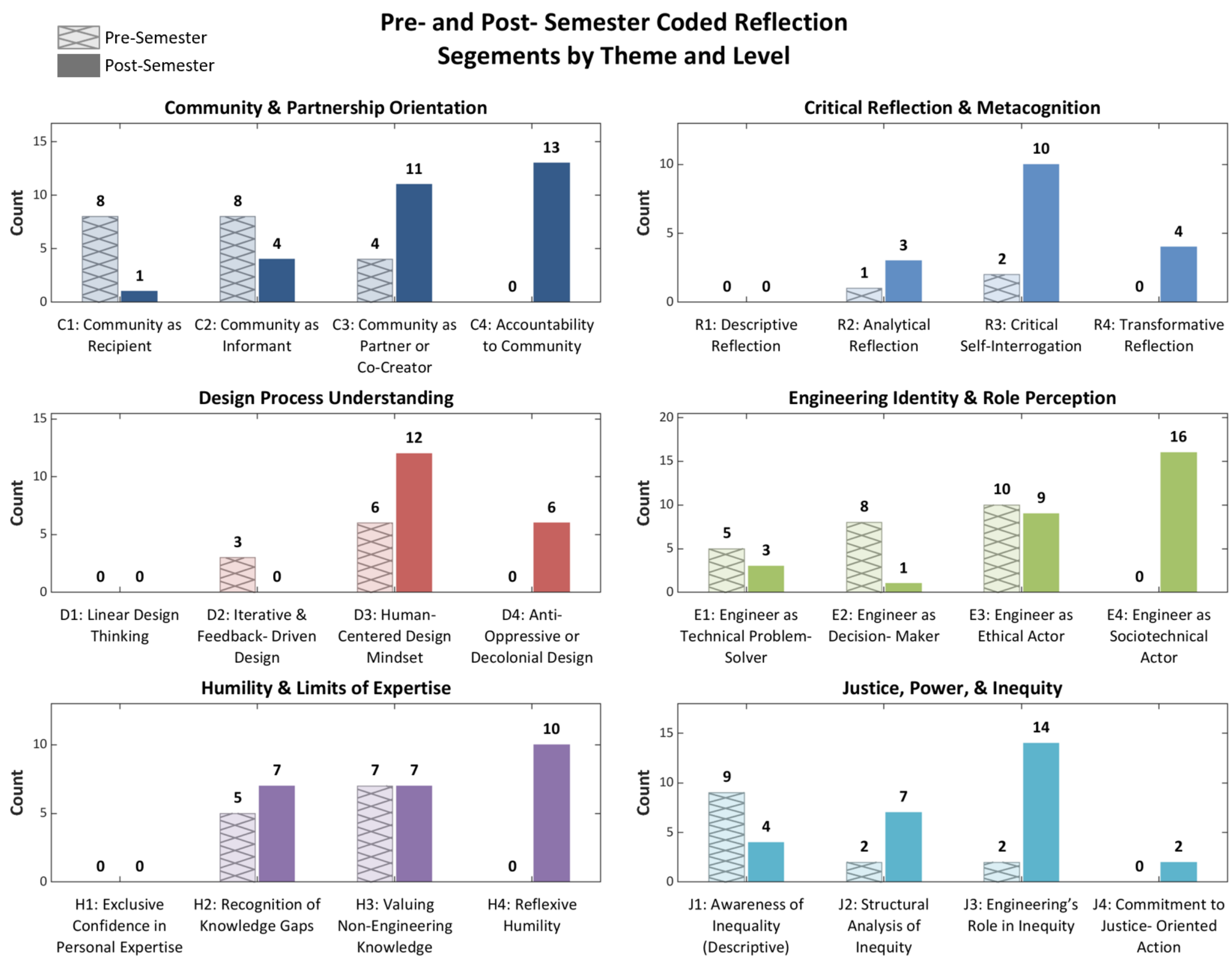

Figure 4. Pre- and post-semester coded reflection segments by theme and reflective level. Each panel shows one theme, where a theme represents a domain of student thinking (e.g., community partnership, design, reflection, ethics, identity). Within each theme, codes are organized along ordered levels representing qualitatively different ways of reasoning about the same topic. Lower levels reflect more immediate, descriptive, or role-bounded framings, while higher levels reflect broader scope, integration of context, and greater ethical or reflexive complexity. Bars represent the frequency of coded analytic text segments (not unique student counts) identified in student reflections at each level for six reflection themes. For each level, lighter hatched bars indicate pre-semester reflections and darker solid bars indicate post-semester reflections. Counts are not mutually exclusive at the student level, as individual reflections may contain multiple coded segments spanning different levels within a theme.

Initial reflections were dominated by lower-level orientations across themes, characterized by descriptive accounts of experiences, technical or role-bounded framings of engineering, and awareness of social issues without extended analysis. These patterns are consistent with the survey findings showing high baseline agreement on openness- and values-based components, suggesting that many students entered the course already endorsing inclusive or justice-oriented ideals, but without deeply articulated sociotechnical reasoning. For example, in the Community and Partnership Orientation panel, early reflections often framed community members primarily as sources of information or feedback:

> "I took a global health class two years ago, and our goal was to design a solution for those in the [local] community. We discovered the need for accessible resources for pregnant and postpartum mothers." (Pre-semester, C1: Community as Recipient).

Similarly, in Engineering Identity and Role perception, early reflections valued wisdom in the context of engineering as being related to experience and ability to make better design decisions:

> "Wisdom in engineering means knowing how to work effectively with others and being knowledgeable about content, applications, design, and mistakes. Learning from mistakes definitely builds wisdom in a field where you have to be very precise." (Pre-semester, E1: Engineer as a Technical Problem-Solver).

By contrast, final reflections contained a greater number of coded segments overall and exhibited broader representation across higher levels of each continuum. These higher-level codes reflect increases in survey components related to sociotechnical integration and community efficacy. In the same Community and Partnership Orientation panel, the post-semester reflections displayed an expanded discussion of partnership dynamics, co-creation, and accountability to affected communities:

> "Designing well for someone else means allowing community partners to guide projects… Input from community partners should matter most and drive the direction of the project in a substantial way." (Post-semester, C3: Community as Partner or Co-Creator).

In C4, Accountability to Community, students went so far as to (rightly so) critique the short duration of the course and suggest ways in which accountability to their partners could be maintained.

The most pronounced qualitative shifts were observed between the Critical Reflection and Metacognition panel and Justice, Power and Inequity panel, which in combination align with the survey finding that Critical Reflection showed the largest positive pre–post change. Survey data show qualitative evidence of students moving from surface-level recognition of inequity toward explicit interrogation of power, privilege, and dominant assumptions. Pre-semester reflections commonly acknowledged social issues without interrogating underlying assumptions:

> "One technology that treated people unfairly is AI in facial recognition. These algorithms demonstrated higher rates of error in identifying people with darker skin due to biased training data." (Pre-semester, J1: Awareness of Inequality (Descriptive)).

By the end of the course, students more frequently demonstrated epistemic self-interrogation and recognition of uncertainty:

> "I think this course made me far more aware of injustices in global health and the role engineering plays in them. I hadn't really thought before about how much regulations, patents, insurance, and the money and power behind them decide what becomes accessible and for whom…In response, I tried to be more intentional about the choices I made, to think more about equity and feasibility, and to pay attention to whose voices were centered in the design process." (Post-semester reflection, R4: Transformative Reflection).

Shifts in Engineering Identity and Role Perception and Humility and Limits of Expertise help contextualize the slight negative change observed in the View of Engineering survey component. Rather than signaling disengagement, post-semester reflections often expressed tempered confidence and recognition of the need (and difficulty) in thinking about societal and ethical implications as an engineer:

> "Reflecting on our course discussions and project work, I realized that I had underestimated how deeply social, cultural, and lived experiences shape the success of engineering solutions, especially in health-related contexts. This course challenged my assumption that technical correctness alone was enough." (Post-semester reflection, E4: Engineer as a Sociotechnical Actor).

Overall, students more frequently noted the importance of partner relationships, acknowledged uncertainty and the limits of their own expertise, considered structural and systemic influences on engineering outcomes, and reflected on the broader implications of design decisions beyond technical performance. These qualitative shifts align most closely with the quantitative components that showed the largest directional changes: Critical Reflection, Integrating Social Concerns into Engineering Practice, Justice Norms, and Self-Efficacy.

While lower-level orientations remained present in final reflections, they increasingly co-occurred with higher-level framings, indicating that students were not abandoning technical or descriptive modes of thinking, but rather embedding them within more complex, context-aware, and ethically oriented modes of reasoning by the end of the course. This pattern suggests developmental layering rather than replacement, consistent with sociotechnical learning theories that conceptualize growth through adding new and complex layers of understanding rather than replacing earlier ideas entirely [31], [52].

6. Conclusion

This study examined sociotechnical and justice-oriented learning outcomes in a senior biomedical engineering capstone course that integrates human-centered design, project-based learning, and anti-oppressive pedagogy. By extending prior qualitative work with a mixed-methods assessment strategy, the present analysis provides evidence of developmental shifts in how students reason about engineering design, community partnership, power, and responsibility over the course of the semester. Collectively, these exploratory quantitative and qualitative patterns tell a consistent story of movement toward more reflexive, partnership-oriented, and sociotechnically informed reasoning across the semester; however, given sample-size and single-institution limitations, these findings should be treated as preliminary and in need of replication with larger cohorts.

Several course components appear particularly influential in shaping the observed outcomes. First, sustained engagement with community partners—reinforced through interviews, partner-facing presentations, and documentation of ongoing communication—likely contributed to increases in students' sociotechnical reasoning and community efficacy. Second, the reorganization of instructional content and readings into thematic clusters aligned with design milestones appears to have supported deeper integration of contextual and justice-oriented considerations into technical decision-making, as reflected in gains in critical reflection and qualitative shifts toward higher-level reasoning about power and inequity. The readings, case studies, and discussions likely also contributed to this shift, exposing students to cases in which engineers had failed to account for social and structural context and the consequences that followed.

Importantly, the combination of survey data and reflection analysis suggests that justice-oriented learning in this context is not characterized by wholesale changes in values, but by layered development in how students articulate and apply those values within engineering practice. Qualitative findings help explain the quantitative pattern in which values-based components (e.g., openness and justice attitudes) showed stability, while developmentally demanding components like critical reflection, sociotechnical integration, and justice norms, exhibited the strongest directional growth. While survey measures could identify *where* change appears most likely, the reflection analysis reveals *how* students' reasoning evolved, providing insight into learning processes that are not fully captured by Likert-scale instruments alone. Reflections indicated that technical reasoning and ethical awareness were more often intertwined by the end of the semester, consistent with models of additive and non-linear sociotechnical development.

While the small sample size limits generalizability, this work demonstrates the feasibility and value of systematically assessing anti-oppressive and sociotechnical learning outcomes in capstone design courses. In addition, this study contributes to a broader University initiative to integrate virtue ethics into engineering education, in which explicit character strengths are identified and emphasized across courses. The results presented here are used both to identify character strengths that align most closely with this capstone experience and to establish baseline data prior to future course iterations that more intentionally nurture these strengths through targeted assignments and instructional practices.

By engaging students in community-partnered design, structured reflection, and explicit consideration of power, responsibility, and sociotechnical context, this capstone model supports a form of professional engineering identity formation that is essential across engineering disciplines. As engineering practice continues to operate within an increasingly inequitable and crisis-prone world, courses that intentionally integrate technical rigor with ethical reasoning and moral development may offer a valuable model for preparing all engineering students to navigate the responsibilities and impacts of their work.

7. Authorship Reflexivity Statement

Course Developers and Instructional Team: As white, cis-female researchers studying and teaching at Duke University, a mid-size, wealthy, predominantly white private institution in the southern part of the United States, we, as authors, acknowledge our position as students and continuing learners when it comes to equitable design and partnerships between universities and communities both local and across the globe. We made attempts to center voices different from our own across the syllabus, cases, and projects, though we welcome any suggestions towards our goal of continuous improvement in this area. We both understand the privilege we hold and how we have benefited from the systemic inequity that we have aimed at fostering better awareness of in our students.

Fall 2025 Instructor: As the instructor delivering the lecture-based components of this course, I facilitated materials developed by the broader instructional team. The course themes closely align with my work in translating women's cancer technologies into real-world clinical settings, allowing me to draw on examples and reinforce concepts related to access, sustainability, and community-engaged design. Having grown up in India, a country shaped by colonial histories and structural inequities, I can authentically engage with students on discussions of power, access, and global health. At the same time, engaging with the course material was, in some ways, a revelation for me as an educator; despite having taught design, I had not previously considered how to explicitly incorporate my own experiences or sociocultural perspectives into design instruction. This realization reinforced the importance of foregrounding these dimensions and highlighted the need to more intentionally integrate them into future design courses.

Combined Instructional Team: With every project, design decisions were proposed or approved by community partners before iteration with local sustainability at the forefront. It is the goal for every project to conclude with the complete handover of prototypes, design files, and training documents to be owned by the community partners. We extend sincere thanks to our community partners for working with us and our students and acknowledge that the constraints of a one-semester design course may impose tighter timelines onto partners.

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Appendix A: Likert-Items for Pre/Post Semester Reflections

Global Engagement Survey [33]

Openness to Diversity:

1. I am able to communicate in different ways with people from different cultures.
2. I enjoy when my friends from other cultures teach me about our cultural differences.
3. I am open to people who strive to live lives very different from my own lifestyle.

Cultural Adaptability:

4. I often adapt my communication style to other people's cultural background.
5. I can easily adapt my actions in response to changing circumstances.
6. I have a hard time working with people who are different from me. *(reverse coded)*

Critical Reflection:

7. I carefully consider how privilege affects people's opportunities.
8. I carefully consider how dominant cultural assumptions reinforce inequalities.
9. When I stop to consider what I know about the world, I realize that even my strongest "truths" are open to change.

Global Sociotechnical Competency Scale [37]

Integrating Social Concerns:

10. I feel confident talking with the people who will be affected by my engineering design projects.
11. I seek to integrate the concerns of potential users into my design projects.
12. I feel confident integrating perspectives from non-engineers into my engineering design projects.

Self-Efficacy:

13. I am confident in my abilities as an engineer.

View of Engineering:

14. I find fulfillment in engineering.
15. I can make positive changes in communities through engineering.

Engineering Social Justice Scale [31]

Justice Attitudes and Intent:

16. I believe that it is important to make sure that all individuals and groups affected by an engineering decision have a chance to speak and be heard, especially those from traditionally ignored or marginalized groups.

17. I believe it is important that engineers talk to others about societal systems of power, privilege, and oppression.
18. I believe it is important that engineers try to change larger social conditions that cause individual suffering and impede well-being.
19. In the future, I will use engineering tools and problem-solving approaches to ensure that all individuals and groups have a chance to speak and be heard.
20. In the future, I intend to talk with other engineers about social power inequalities, social injustices, and the impact of social forces on engineering solutions.
21. In the future, I intend to engage in engineering activities that will promote social justice.

Justice Norms:

22. I feel confident in my ability to talk to others about social injustices and the impact of social conditions on health and well-being as they relate to engineering.
23. Other engineering students around me are engaged in activities that address social injustices.
24. Other engineering students around me are aware of issues of social injustices and power inequalities in our society.

Community Efficacy:

25. I am certain that if I try, I can use engineering to have a positive impact on my community.

Appendix B: Short-Answer Prompts for Pre/Post Semester Reflections

Pre-Semester:

Purpose: The purpose of the initial reflection is to provide an opportunity for each student to express their personal experience with design, perceptions of global health, and rationale of choosing BME 462 as their senior design course.

Name:

Intended Plan after Graduation (as of August 2025):

Opened-Ended Questions:

1) When and why did you choose BME? Has your perspective on BME changed since then?
    a) What kind of person do you want to become as an engineer and what do you want your role/impact to be? What qualities do you hope to embody—technically and ethically?
2) What is your experience with global health, equity, or community-based design? Provide examples that have had an impact on you.
3) What is your experience with design or building? Where and how have you engaged in the design process previously?
4) What motivated you to enroll in this design course? Discuss any specific interests or goals you had when you chose this course. What do you hope to learn through it?
5) What does it mean to design well for someone else? What factors do you usually consider and what do you think should matter most?
6) What do you think makes a design just or unjust? Can you think of a technology or design that treated people unfairly?
7) When working in a team or on a project, how do you usually respond when you're uncertain—or when someone disagrees with you?
    a) What does humility look like (or not look like) in those moments?
8) What does wisdom mean to you, if anything, in the context of engineering?
    a) Is it something you associate with the work of engineers? Why or why not?

Post-Semester:

Purpose: The purpose of the reflection is to provide an opportunity for each student to express their personal experience with design and this course and perceptions of global health.

Name:

Intended Plan after Graduation (as of December 2025):

Opened-Ended Questions:

1) Reflecting on our course discussions and your project work, has this course challenged any assumptions you previously held about engineering, health, or the communities you serve? If so, how did you respond to those challenges?

2) Reflect on your team's collaboration. How did each member of your team provide leadership and create a collaborative and inclusive environment that established goals, planned tasks, and met objectives? Or how did your team fall short?

    a. Where did your team practice justice, humility, or wise decision-making—and where could it have improved?

3) What do you think is the true purpose of this course? Should it exist at all or in its current form? In addressing real-world challenges, are we doing more good than harm?

In addition, now that you've completed the course, how would you answer these questions that were also posed in the initial reflection?

4) What kind of person do you want to become as an engineer and what do you want your role/impact to be? What qualities do you hope to embody—technically and ethically?

5) What does it mean to design well for someone else? What factors do you usually consider and what do you think should matter most?

6) What do you think makes a design just or unjust? Can you think of a technology or design that treated people unfairly?

7) When working in a team or on a project, how do you usually respond when you're uncertain—or when someone disagrees with you?

    a. What does humility look like (or not look like) in those moments?

8) What does wisdom mean to you, if anything, in the context of engineering?

    a. Is it something you associate with the work of engineers? Why or why not?

Appendix C: Codebook and Descriptions

Community and Partnership Orientation

1. *C1: Community as Recipient*. Communities are described primarily as beneficiaries or end users of engineering solutions, with little attention to dialogue or shared decision-making.
2. *C2: Community as Informant.* Communities are framed as sources of information or feedback that inform design decisions, while authority remains primarily with engineers.
3. *C3: Community as Partner or Co-Creator.* Communities are described as active collaborators and a source of shared authority in problem definition and solution development.
4. *C4: Accountability to Community.* Students articulate an emphasis on long-term responsibility, harm reduction, community ownership, and sustainability.

Critical Reflection & Metacognition

1. *R1: Descriptive Reflection.* Description of experiences without interpretation or critique.
2. *R2: Analytical Reflection.* Students analyze experiences or explain what was learned without examining personal assumptions.
3. *R3: Critical Self-Interrogation.* Students question/examine their own beliefs, assumptions, positionality, or prior thinking.
4. *R4: Transformative Reflection.* Students explicitly articulate a changed worldview or professional identity.

Design Process Understanding

1. *D1: Linear Design Thinking.* Design framed as stepwise, solution-first, or technically bounded.
2. *D2: Iterative & Feedback-Driven Design.* Recognition of iteration, testing, failure, and learning cycles.
3. *D3: Human-Centered Design Mindset.* Emphasis on empathy, context, reframing problems around people.
4. *D4: Anti-Oppressive or Decolonial Design.* Design is situated within broader social, cultural, and power contexts, with attention to equity and harm. Explicit critique of top-down, colonial, or extractive design practices also included.

Engineering Identity & Role Perception

1. *E1: Engineer as Technical Problem-Solver.* Engineering framed as primarily technical, neutral, or solution-focused without social or ethical context.
2. *E2: Engineer as Decision-Maker.* Recognition that engineering choices influence outcomes and carry responsibility beyond technical success.
3. *E3: Engineer as Ethical Actor.* Explicit acknowledgment of ethical responsibility, harm, accountability, or moral considerations in engineering.
4. *E4: Engineer as Sociotechnical Actor.* Engineering understood as embedded within political, cultural, economic, and social systems.

Humility & Limits of Expertise

1. *H1: Exclusive Confidence in Personal Expertise.* Emphasis on engineer authority or certainty; little recognition of limits of knowledge.
2. *H2: Recognition of Knowledge Gaps.* Acknowledgment of uncertainty, incomplete knowledge, or need to learn.
3. *H3: Valuing Non-Engineering Knowledge.* Recognition of community, clinical, or lived experience as legitimate expertise alongside other types of soft engineering skills.
4. *H4: Reflexive Humility.* Explicit self-critique of assumptions, biases, saviorism, or positionality.

Justice, Power, and Inequity

1. *J1: Awareness of Inequality (Descriptive).* Recognition that disparities or inequities exist without systemic analysis.
2. *J2: Structural Analysis of Inequity.* Discussion of power, history, colonialism, or systemic forces shaping inequity.
3. *J3: Engineering's Role in Inequity.* Recognition that engineering can reinforce or disrupt inequitable systems.
4. *J4: Commitment to Justice-Oriented Action.* Students articulate responsibility or intent to act to promote justice in future work.