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Graduate Student Development in a Required Course on Engineering and Research Skills that is Contextualized with Social Justice Content

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1. Introduction

Engineering research affects society in ways that can either reduce or reinforce inequity. Yet traditional engineering graduate curricula typically emphasize technical mastery while omitting structured engagement with social, ethical, and systemic contexts. This omission contributes to a persistent disconnect between research innovation and its societal consequences.

With more than 75% of Northwestern University's chemical engineering Ph.D. graduates entering industry in sectors such as pharmaceuticals, energy, materials, consumer products, electronics, food processing, biotechnology, and environmental protection, they are positioned to influence product and process development with significant consequences for human well-being and environmental sustainability. It is important that engineering researchers understand how their innovations *affect* society and how their work is *shaped by* social, economic, regulatory, and environmental contexts. Graduate-level preparation must extend beyond technical competence to develop researchers capable of situating their work within broader societal structures and making informed, responsible design and research decisions.

This paper introduces a required two-quarter professional development course designed to address the lack of these core competencies into research practice. The course integrates technical skill development with anti-racism, diversity, equity, inclusion, justice, and contextual analysis into engineering research training. We present a portion of this larger work, including:

- A contextualized equity-driven framework guiding curriculum and assessment
- Course structure and pedagogical design
- Patterns in how students articulate societal contexts, justice considerations, and ethical decision-making
- Emerging challenges and opportunities in teaching participatory engagement

2. Motivation for a Graduate Professional Development Course as a Site for Justice-Oriented Learning

Graduate students encounter real-world research decisions early in their training. Yet few engineering departments offer structured opportunities to examine inequity, positionality, and ethics as integral components of research practice. Required responsible conduct of research (RCR) training is often limited to procedural topics such as data management, conflicts of interest, and human subjects protections. Although these topics are essential, we argue that research competence also requires the ability to understand the social and environmental impacts of engineering work and to incorporate those considerations into engineering decision making. To address this gap, we adapted a graduate research skills course to position contextual awareness and justice not as ancillary concerns but as core research skills, consistent with calls in engineering

education literature to integrate ethics, context, and reflective practice throughout technical training[1].

3. Course Description

3.1 Course Goals

The adapted professional development course expands the concept research skills to include contextual, ethical, and equity-oriented competencies. Students develop a shared language and understanding around concepts of anti-racism, equity, diversity, inclusion, and justice, and engage in reflective practices to explore identity, positionality, and bias. Through case studies, students analyze inequities in STEM, connecting research impacts, including benefits and harms, to broader systemic structures. Course assignments provide structured opportunities to practice ethical and equity-centered decision-making, and students ultimately propose plans for integrating equity-driven approaches in their own research practice.

3.2 Two-Quarter Structure

The course is intentionally structured as two non-sequential fall quarter offerings aligned with distinct stages of doctoral students' development. The first quarter is taken during students' initial fall term, when they are newly arrived, primarily engaged in coursework, and have not yet fully entered a research group. This first offering focuses on skills and orientations relevant to this early stage, including strategies for thriving in graduate school, research safety, preparation for teaching assistant roles, and foundational concepts related to inequity, inclusion and exclusion, and how research impacts are internalized and experienced[1]. The second quarter is taken during students' second fall term, after they have joined a research laboratory and are immersed in research practice. At this stage, students require more advanced professional competencies, including technical communication, literature searching, and structured frameworks for integrating contextual awareness, impact analysis, and ethical reasoning directly into their own research. The spacing between the two offerings allows students to move from conceptual grounding to application once they are positioned to reflect meaningfully on their own research decisions. In both quarters the content is supported by structured reflective journaling.

3.3 Pedagogical Foundations

Because discussions in this course regularly engage with inequity, bias, and personal experience, both students and instructors must be prepared for conversations that may be emotionally difficult. Instructors and teaching assistants are trained to manage "hot-moments" and de-escalate challenging interactions. Students and the instructor co-create community guidelines for conversations. While the instruction is discussion based, students are encouraged to participate in discussions but are never forced to speak if they are uncomfortable. Class discussions occur in both large and smaller group settings, and reflective journal entries are submitted anonymously so that students can express their thoughts freely.

4. Equity-Driven Contextualization Framework

The equity-driven contextualization framework developed for this course structures both teaching and analysis of student work around four interrelated dimensions: Contextual Understanding, Impact Analysis (benefits, harms and inequities), Participatory Engagement, and Ethical Decision-Making Integration.

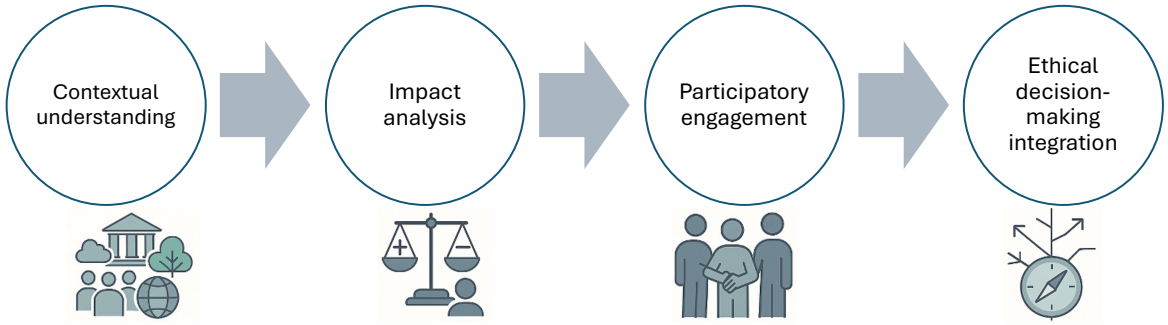

Figure 1. Equity-Driven Contextualization Framework with four dimensions: contextual understanding, impact analysis, participatory engagement, and ethical decision-making integration. The process is underpinned by reflective practices.

The framework was built on several foundational theories in social justice, human rights, contextual understanding, and reflective practices, framing engineering as socially situated, ethically consequential, and participatory[2], [3]. Situated learning and communities of practice scholarship emphasize that engineering knowledge and professional identity are shaped by specific social, institutional, and political contexts, motivating the framework's focus on contextual understanding[4], [5]. Critical pedagogy and critical consciousness inform the framework by grounding reflection on positionality, identity, and the ways engineers' roles influence how problems are defined and whose knowledge is valued[6]. Engineering for social justice and human rights scholarship highlights how technical systems interact with social, economic, political, and environmental systems to reproduce or challenge structural inequities, informing the dimension centered on analyzing benefits, harms, and rights-based impacts of engineering work[7], [8]. Participatory and co-design literature emphasize the ethical importance of engaging those affected by technologies, supporting the framework's focus on stakeholder engagement throughout the research and design process[9]. Finally, reflective practice theory underscores that contextual and ethical awareness must be integrated into engineering judgment and technical decision-making rather than treated as external constraints, reinforcing the framework's focus on embedding equity and human rights considerations directly into engineering choices[10].

These theoretical commitments were operationalized into four dimensions through iterative refinement of case-based, discussion-driven, and reflective learning activities. The resulting framework supports both critical analysis and actionable, justice-oriented engineering practice by organizing the theory into an actionable engineering workflow from understanding (context, systems, stakeholders) to evaluation (harms, benefits, inequities) to participation (engaging affected communities) to decision-making (integrating insights into engineering judgment), aligning with engineers' problem-solving sequence. The framework works well with realistic

situations in case studies, design projects, and research training. It is not just ethics modules; it is social justice and contextual awareness embedded in engineering practice.

5. Methods

The primary artifact analyzed in this study is a collaborative two-page research brief, referred to here as a white paper, completed in small groups at the end of the second quarter. Students were asked to develop a proposal addressing one or more of the National Academy of Engineering (NAE) Grand Challenges. The white paper required teams to (1) identify the relevant Grand Challenge domain, (2) situate their proposed approach within existing efforts, (3) articulate the unique strengths of the research team, and (4) analyze anticipated scientific and societal outcomes, including benefits, harms, and impacts on affected communities.

Students completed the white papers in teams, with team size varying by cohort (two students per team in 2023, three in 2024, and six in 2025). Students first completed a survey indicating their preferred Grand Challenge domain, and teams were formed to align students by shared domain interest. White papers were graded at the group level.

Students were provided with a grading rubric focused on completeness, teamwork, and alignment with stated learning outcomes related to anti-racism and equitable research practice. However, the equity-driven contextualization framework used in this study for analysis and scoring was not shared with students. This framework was applied post hoc as an analytic lens to evaluate how students articulated context, impacts, participatory engagement, and ethical decision-making integration in their research briefs.

All white papers were independently reviewed by the course instructor and one teaching assistant. The same instructor-TA pair evaluated all white papers within a given year, using the four-dimension equity-driven contextualization rubric (Table 2) with scores ranging from 1 (minimal understanding) to 4 (multi-dimensional understanding). Scores reflect group-level performance rather than individual student assessment.

To illustrate usage of the rubric, the 2023 "Engineering Better Medicines" team wrote "*The current economic landscape in the pharmaceutical and biotechnology industry does not contain the necessary structures and financial incentives for companies or research labs to dedicate money and resources for the production of cheaper raw materials or development of biosimilar or novel molecules that have relevant existing therapeutic value but with improved accessibility in more resource limited settings."* This discussion of the current economic and systemic contexts combined with their identifying global access issues, "*…the disparity in access across the globe became particularly evident during the most recent COVID-19 pandemic, where vaccines and medicines required low temperature storage and healthcare infrastructure to administer,"* earned the team a score of 4 in Contextual Understanding.

Table 2. Abbreviated rubric for the four dimensions of the equity-driven contextualization framework.

	4 (Multi-dimensional understanding)	1 (Minimal understanding)
Contextual Understanding	Provides multi-dimensional analysis of the societal, cultural, political, environmental, historical, and systemic context of the work; identifies, with nuance, who is impacted, included, or excluded and why.	Shows minimal understanding of the context or affected groups.
Impact Analysis	Analyzes both the positive and negative outcomes of engineering solutions, particularly their impacts (benefits, burdens, risks; both intended and unintended) on affected people. Analyzes how systemic and/or historic inequities impact the problem or project; connects these to specific structures (e.g., racism, colonialism, classism).	Does not identify or meaningfully analyze injustice or inequity.
Participatory Engagement	Ensuring that affected communities, individuals, and stakeholders are actively and inclusively engaged in all stages of the research or design process. Considers power dynamics and cultural awareness when engaging with communities and affected people.	Fails to consider stakeholder input or engagement.
Ethical Decision-making integration	Integrates the insights gained through contextual understanding and impact analysis into engineering decisions. Demonstrates ethical reasoning grounded in contextual understanding, justice, and responsibility during decision-making. Proposes equity-oriented actions that improve conditions (elimination, reduction, or prevention of harms) for impacted communities and people.	Decision-making happens in the absence of contextual, ethical, or equity-oriented reasoning, or the considerations are underdeveloped.

**Throughout this framework, we use terms such as *communities* (geographic or cultural), *affected persons* (both included or excluded groups; those that benefit and those that are exposed to burdens), and *stakeholders* to describe people who are impacted by, benefit from, or are marginalized by engineering decisions. We encourage students to identify and engage with these groups thoughtfully and respectfully, recognizing both their agency and their vulnerability in different contexts.

Three cohorts are represented in this study. The cohort labeled 2023 entered the program in Fall 2022 (n=15) and completed the second quarter of the course in Fall 2023. The second cohort (n=31) completed the second quarter in Fall 2024. The third cohort (n=23) completed the second quarter in Fall 2025. The analysis presented here focuses on white papers produced at the end of the second quarter for each cohort.

Each cohort represents a distinct group of students; there is no overlap of students across cohorts in the second-quarter analysis. The same instructor taught the courses from Fall 2022 through Fall 2024, while a different instructor taught the second quarter course in Fall 2025. Teaching assistants varied across years.

6. Limitations

(1) Group size – Because white papers were produced collaboratively and team sizes varied across cohorts, scores reflect group-level synthesis rather than individual mastery and may be influenced by group dynamics.

(2) Framework – Because the equity-driven contextualization framework was used analytically for grading instead of instructionally in the assignment materials, scores reflect demonstrated capacity rather than explicit compliance with rubric criteria.

(3) Instructional continuity – A different instructor taught the second-quarter course in Fall 2025, which may have influenced instructional emphasis or student expectations. Instructional changes included a new emphasis on writing for research proposals and grants.

7. Results

Our two main questions in this research were: (1) how do graduate students demonstrate capacity across different dimensions of equity-driven contextualization, and (2) where are the persistent challenges as students move from early to more immersive stages of research training? We sought to determine students' relative strength across the dimensions of the framework, whether there were patterns of growth (or stagnation) over time, and where instructional support is still needed.

Figure 2 summarizes the cohort performance across the four dimensions. The performance in each dimension is summarized in a box and whiskers plot with three panels, one per year: 2023 (5 teams), 2024 (9 teams), and 2025 (4 teams). Each panel shows multiple boxplots, corresponding to the four dimensions of the framework rated from 1 (minimal understanding) to 4 (multi-dimensional understanding).

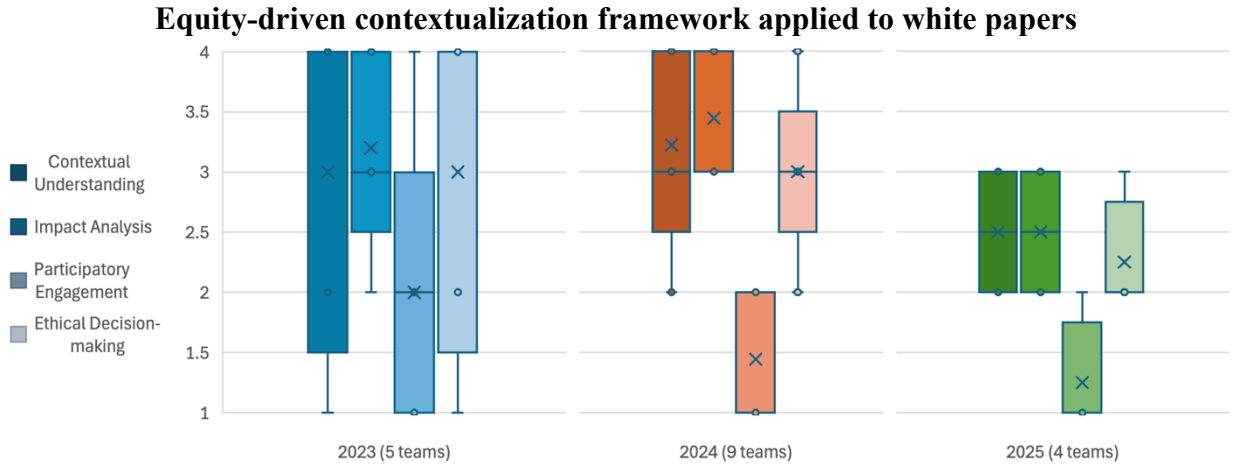

Figure 2. By cohort analysis of performance in the four dimensions of the equity-driven contextualization framework for students in the 2023, 2024, and 2025 course.

Across cohorts, the average rubric scores show a modest downward shift, accompanied by reduced variability in some dimensions, especially in the 2025 cohort. Given concurrent changes in team size (two students per team in 2023, three in 2024, and six in 2025), an instructor change in 2025, and modifications to the case studies used in class to foreground elements of the equity-driven contextualization framework, these shifts should not necessarily be interpreted as a decline in student capacity. Rather, the results suggest that later cohorts engaged with the framework under differing conditions.

The 2024 and 2025 cohorts were introduced to concepts from the equity-driven contextualization framework earlier than the 2023 cohort. In addition, the 2025 cohort worked in much larger teams. We hypothesize that these two factors likely shaped how ideas emerged, were negotiated, and ultimately appeared in the written papers. In particular, the six-person teams in 2025 appear to have altered how ideas survived the drafting process.

Compared to the two-person teams in 2023, the larger six-person teams in 2025 more often negotiated uncertainty toward consensus, producing cohesive and rhetorically confident proposals

that emphasized solution-oriented outcomes, analogous to strong fellowship proposals or funding pitches. We don't believe this is reduced critical engagement. We interpret this as an outcome of larger-group dynamics in which divergent or uncertain perspectives may be negotiated rather than preserved as productive discomfort. Teams in 2025 positioned their proposals with verbs like "enables," "provides," and "addresses."

> "*General society will benefit from this stronger public health infrastructure, enabling on-demand intervention before diseases can become widespread*." – from "Sense & Respond mRNA Therapeutics" 2025.

In contrast, the 2023 cohort's writing more frequently surfaced unresolved tensions, tradeoffs, and doubts regarding the limits of engineering intervention. At the time, those students were still encountering equity and justice frameworks, and their narratives reflect a more exploratory stance that grapples with uncertainty and acknowledges tensions that cannot be fully resolved. The later cohorts, having internalized clearer expectations for what "responsible engineering" should look like, more often wrote toward resolution rather than open-ended grappling. The 2023 teams positioned their proposals with verbs like "raises concerns" or "may create."

> "*Our strategy would highlight the need for individually tailored approaches to carbon capture implementation. Every community is unique and as a result, there cannot be one broad approach."* – from "Develop Carbon Sequestration Methods" 2023.

To better understand the variability underlying these cohort-level patterns, we next examined group-level scores across dimensions and then focused specifically on participatory engagement, the most persistently challenging dimension.

Contextual Understanding, Impact Analysis, and Ethical Decision-making for All Teams

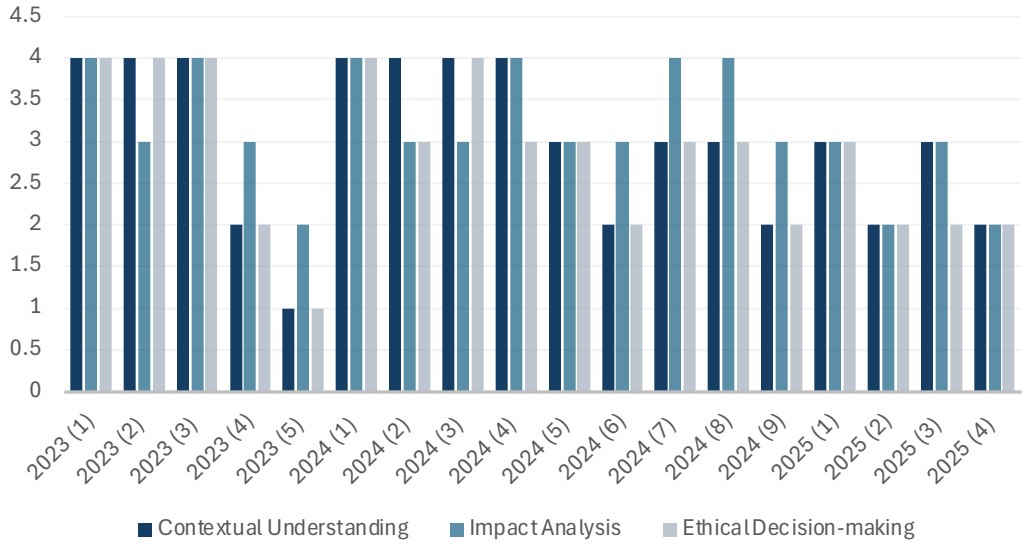

Figure 3. Raw scores for all teams [*year(team#)*] for three dimensions in the framework: Contextual Understanding, Impact Analysis, and Ethical Decision-making using the rubric on a scale of 1 (minimal understanding) to 4 (multi-dimensional understanding).

Looking into the variability in the data we noted that across all teams students demonstrated the strongest performances in contextual understanding and impact analysis (Figure 3). Groups that looked beyond the technical challenges were able to situate their proposed projects within broader social, environmental, and systemic contexts. Similarly, identifying the potential benefits and harms of research proved to be as accessible to students as contextual analysis. Students could recognize both intended outcomes and unintended inequitable impacts of their proposed research. While many students could identify positive outcomes, articulating potential harms or inequities required deeper reflection on the intersection of technical decisions with social and environmental systems.

Ethical and equity-informed decision-making (Figure 3) posed some challenges in translating contextual and impact awareness into technical decisions. We believe that repeated practice in case studies and reflection during the course may support the development of ethical reasoning as it relates to technical problem-solving.

We noted that participatory engagement was consistently the most challenging dimension for students. While course discussions used terms such as communities, affected persons, included or excluded groups, and stakeholders to describe people who are impacted by, benefit from, or are marginalized by engineering decisions, many students struggled to translate this language into concrete engagement strategies. As seen in Figure 4, across cohorts, students had difficulty articulating how affected communities could meaningfully participate in research, reflecting limited experience and confidence in accessing or collaborating with stakeholders. This suggests that students either (1) lack a clear model of meaningful engagement, (2) feel limited in their access to stakeholders, or (3) perceive engagement as peripheral to technical decision-making.

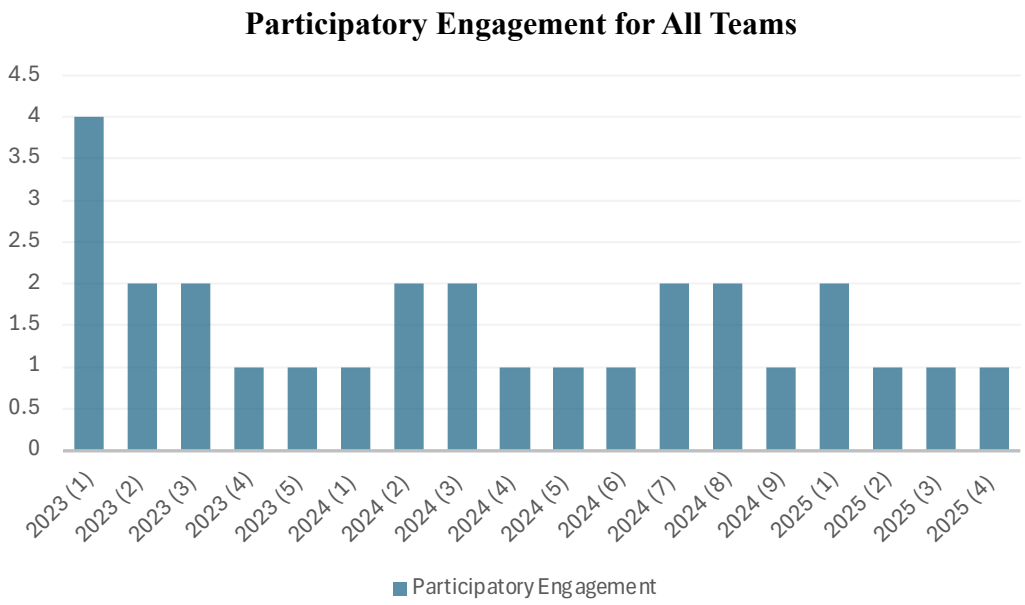

Figure 4. Raw scores for all teams [*year(team#)*] for one dimension in the framework: Participatory Engagement using the rubric on a scale of 1 (minimal understanding) to 4 (multi-dimensional understanding).

8. Conclusion

This paper demonstrates the restructuring of professional development course to prepare students to contextualize their engineering research. The course development went alongside the development of a four-dimension framework for equity-driven contextualization of engineering work. Evidence from student white papers showed contextual, ethical, and reflective capacity. The work samples highlighted the need for and opportunity to create stronger scaffolding of participatory engagement. Overall, the course met our broader goal of preparing engineering researchers to be technically excellent and socially responsible.

In response to our findings, future iterations of the course will incorporate more explicit scaffolding for participatory engagement, including structured examples of stakeholder collaborations in research contexts, guided analysis of realistic engagement constraints, and opportunities for students to practice identifying appropriate roles for community participation without overclaiming access or authority. These changes aim to support students in navigating the tension between ethical awareness and feasible action within research systems.

Citations

[1] K. Chintam *et al.*, "Designing, Codifying, and Implementing Social Justice Content in a Required Course on Engineering and Research Skills for First-Year Graduate Students," presented at the 2023 ASEE Annual Conference & Exposition, Jun. 2023. https://peer.asee.org/43005

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